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# Electronic Control—With Reference to Apparatus Used on a Structural Test Frame.

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By K. C. DERRICK,
Associate I.E.E., A.R.Ae.S., M.A.S.E.E.

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# ELECTRONIC CONTROL — WITH REFERENCE TO APPARATUS USED ON A STRUCTURAL TEST FRAME.

By K. C. DERRICK, Associate I.E.E., A.R.Ae.S., M.A.S.E.E.

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## INTRODUCTION.

THE main purpose of this pamphlet is to introduce the subject of electronics in, as far as possible, a non-technical manner to those engineers and the like who wish to know something about the subject, but have insufficient time to wade through the relevant literature. The bibliography is included at the end for those who wish to study further.

The text of the pamphlet is essentially simple, since it is intended to serve merely as an elementary introduction, and should the reader wish to pursue the subject no further, the time already spent in its perusal will not have been entirely wasted, because some of the potentialities of electronics will then be fairly obvious.

Electronics is correctly defined as the science which deals with the behaviour of free electrons, that is, the control of electrons through space rather than through the more familiar conductor.

When valves, or, to use another popular term, tubes, are used in an electrical circuit, then the expression "electronics" can be correctly applied.

The subject is a prodigious one, and in a short treatise such as this, it is only possible to refer to the salient points of some electronics and associated non-electronics, but there is sufficient, perhaps, to "whet the appetite."

The text is progressive, leading up to a description of an electronically controlled aircraft test frame. The purpose of this frame is to test large aircraft components, such as a wing or fuselage, etc., to destruction, and to simulate those loading conditions experienced during flight.

Acknowledgments are due to the McGraw Hill Book Co. Inc. (New York) for their permission to use some of the diagrams and references from George M. Chute's book *Electronics in Industry*, and to Blackburn & General Aircraft, Ltd. (formerly General Aircraft, Ltd.) for their permission to reproduce diagrams and references to the structural test frame.

## CHAPTER I.

## ELECTRONIC PRINCIPLES—INTRODUCING THE THYRATRON.

### Simple Electric Theory.

An electron is a minute particle of *negative* electricity which, when dissociated from the atom of which it is part, shows none of the properties of ordinary matter. All electrons are similar, no matter with what type of atom they are associated. The electron is nothing but electricity and is the smallest negative quantity of it.

There are $6{\cdot}29 \times 10^{18}$ electrons in a coulomb (one *coulomb per second* is one *ampere*); the radius of an electron is of the order of $10 - {}^{13}$cm.

The exact opposite of the electron is the proton, which consists of positive electricity. The proton and the electron are therefore equal electrical charges, but of opposite sign. Due to an inexplicable phenomenal difference, this has the effect of making the mass of the proton very much greater than that of the electron. The mass of the proton for purely academic interest is $1{\cdot}63 \times 10 - {}^{24}$ grams.

Therefore the mass of the atom is, for all practical purposes, the mass of the protons it contains, the mass of the electron being negligible and consequently can be controlled with the minimum electrical effort, resulting in an instantaneous response to a suitably arranged controlling medium. The various controlling media will be described later.

Under ordinary conditions the electrons of any atoms are firmly held in the atom, and the positive and negative charges neutralise each other as far as efforts external to the atom are concerned.

It is possible, with certain substances, to remove some of the electrons which travel in the outer orbit, if sufficient energy is applied. This alters the state of electrification of the atom, *but not its nature.*

An atom which has either a deficit or surplus of electrons beyond its complement is termed an "ion" and is said to be "ionised."

When a "neutral" atom loses an electron, it becomes a positive ion, and when it gains an electron it is a negative ion.

The "disturbed" atoms always tend to revert to their original neutral state, so that a positive ion will attract electrons, whilst a negative ion will repel them.

The process of ionisation can be achieved in various ways.

This preamble is not intended to thoroughly explain the electron theory, since there are other parts of the atom, such as neutrons and positrons, which have not been mentioned because they are beyond the scope of this treatise. Sufficient has been explained, we hope, to follow the behaviour of electrons through space.

It would be as well at this stage to refer to Fig. 1 which shows a heater glowing in a glass bottle. The small black circles which appear to be displaced from the heater element are the free electrons, wandering, as it were, at random.

If we now refer to Fig. 2 which is a diode, so named because of the additional electrode termed the anode, we see that the heater has now been designated the cathode. If the anode has a positive potential applied to it by the H.T. battery, shown on the left hand-side of the diagram, the negative end of which is connected to the cathode, those electrons which we previously referred to as "wandering at random," now stream with considerable velocity to the anode and thence into the external circuit of the valve by medium of the copper wire, connected from the anode cap of the valve and complete the circuit through the battery.

We see then that electronic flow is taking place through a medium (*i.e.*, vacuum or some inert gas) other than through the more well-known metallic form of conductor, and it is this phenomenon that differentiates the term electronic apparatus from the

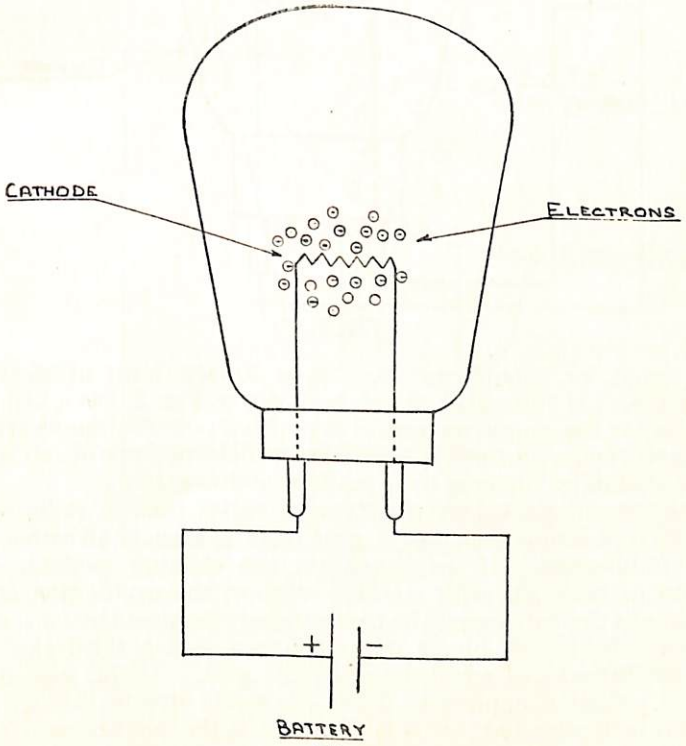



**Fig. 1.**

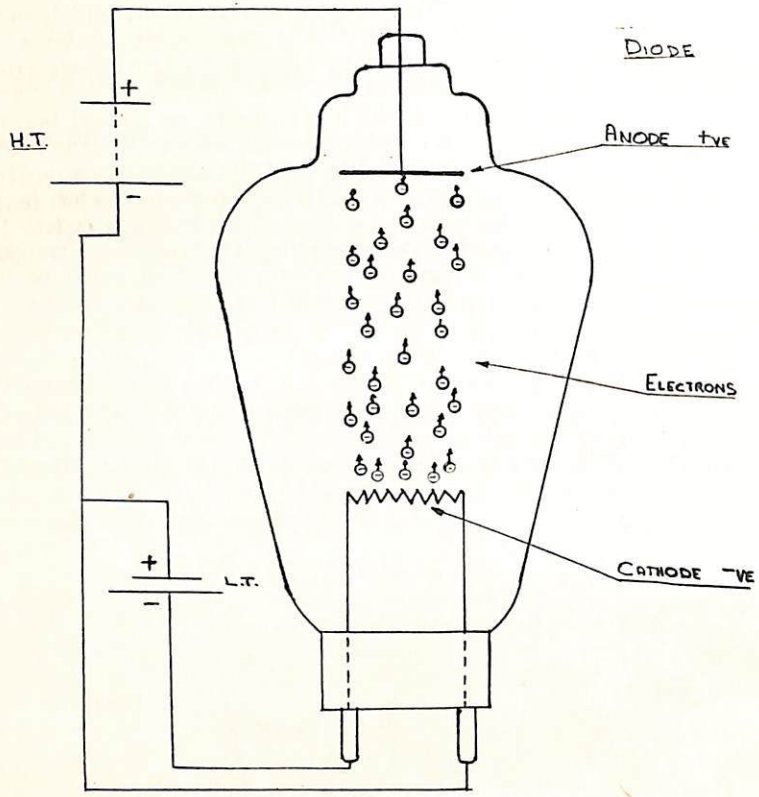



**Fig. 2.**

more usual, or should we say, better known form of electrical conductor. If this valve, which is shown in Fig. 2, has a negative potential at the anode instead of a positive potential no electronic stream will converge upon it, since there will be no force of attraction due to dissimilar charges (*i.e.*, positive and negative).

The current passed by this type of valve, used in radio work, or work of a similar nature, is usually of a very small value, say 1 - 60 milli-amps. If we substitute the existing medium of a vacuum or inert gas with mercury vapour, the conduction across the space of the valve would be tremendously increased by ionisation.

Now referring to Fig. 3 it can be seen that a third electrode has been introduced which is called the grid. If this grid has a positive potential applied to it the electronic stream through any medium is accelerated; this is of course if the conditions referred to in Fig. 2 are still maintained. If on the other hand a negative

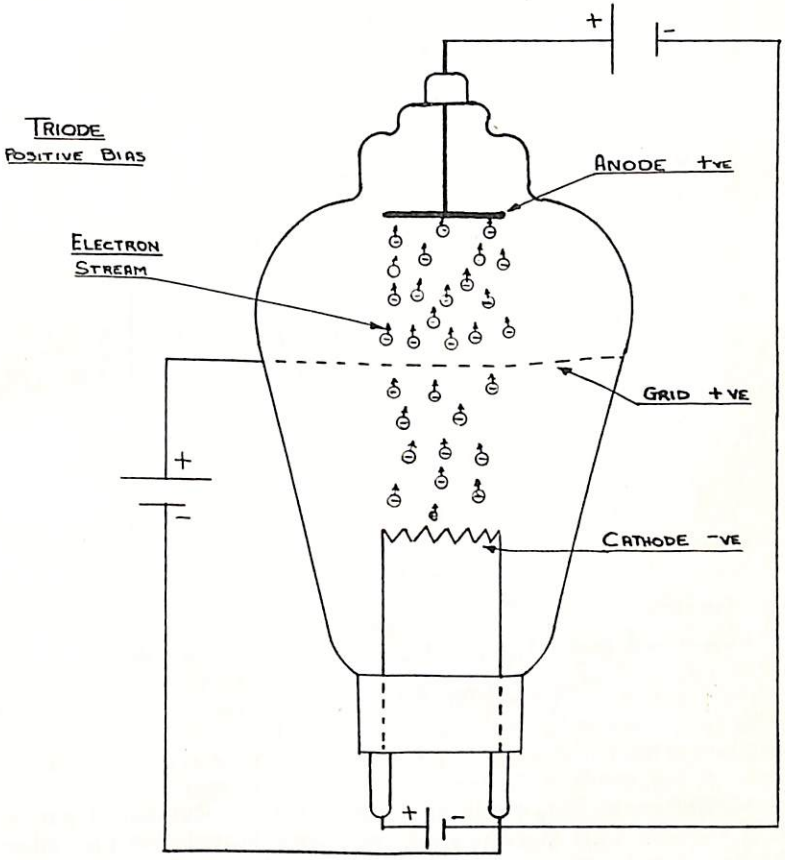

TRIODE
POSITIVE BIAS
ELECTRON STREAM
ANODE +VE
GRID +VE
CATHODE -VE
+
-
+
-
+
-

Fig. 3.

potential is applied to the grid, the electronic stream is decelerated proportional to the amount of negative charge on the grid and at a certain value dependent upon the characteristics of the particular valve the stream is stopped. This condition is referred to as "cut off point" of the valve.

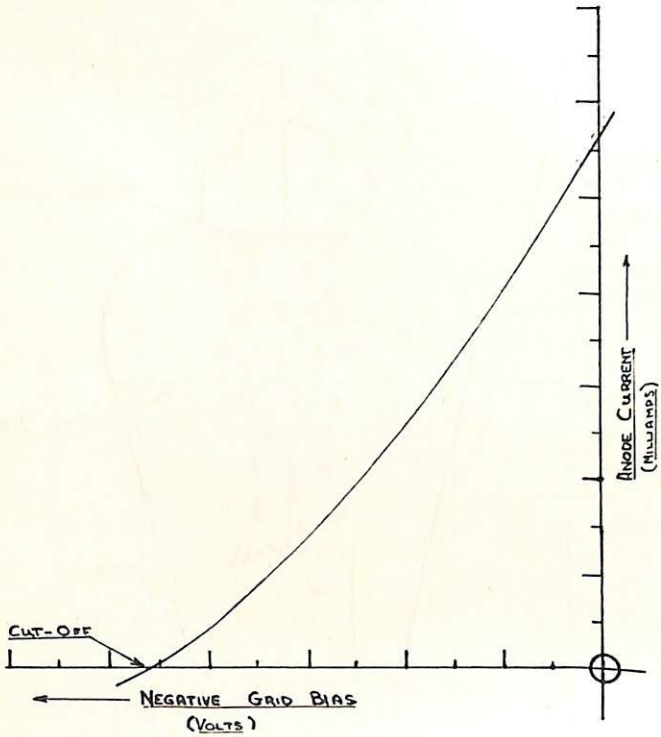



Fig. 4.

Reference to Fig. 4 will show that if anode current is plotted on a vertical scale and the negative charge potential is plotted on the horizontal scale, a curve can be drawn showing the relationship between the current flowing in the anode circuit in relation to the applied grid voltage, which is generally termed bias.

Where the curve touches the grid voltage line a projection can be made along the base line to show that the anode current is zero, and that electronic emission has ceased.

Reference to Fig. 5 shows a pictorial representation of the emission when the valve is operating near the "cut-off point."

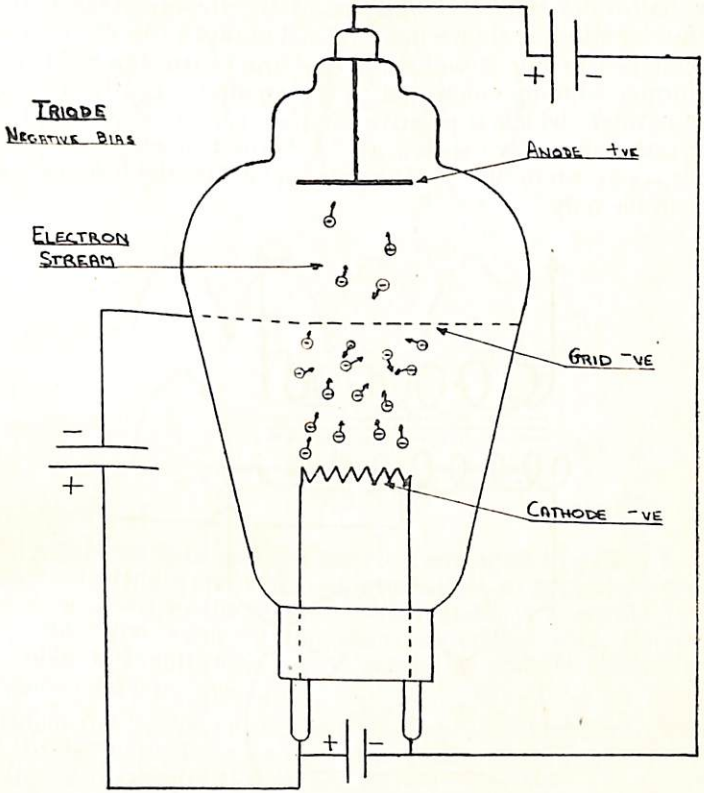



**Fig. 5.**

It can be seen from what has gone before that a variation of potential in magnitude and direction on the grid has a very sensitive control of the current flowing through the valve and its external circuit, and for a very small change in grid voltage with negligible current, very large current can be controlled through the anode circuit ; therefore it can be seen that this valve can amplify very small grid signals into large current changes.

We mentioned earlier that if the anode of the valve was made negative, in relation to the cathode, this would prevent any electronic emission. So if an alternating current is applied to the anode of the valve, it is only during the time that the positive half of the sine wave is being impressed upon it that current will flow through the valve. Therefore, the valve will act as a one-way "street" for the flow of current, and this becomes a half-wave rectifier. We can by the inclusion of another anode pick up the

other half-wave which is out-phased by the inductance of the transformer winding shown in Fig. 6 and obtain a full-wave rectifier.

Reference to Fig. 6 will show that the centre tap point of the transformer winding connected to the anode is negative in respect to the cathode which is positive, and we can, as shown in Fig. 7, convert the sine wave shown at "A" into two pulses of positive current, as shown in "B." The pulse in "C" results from half-wave rectification only.

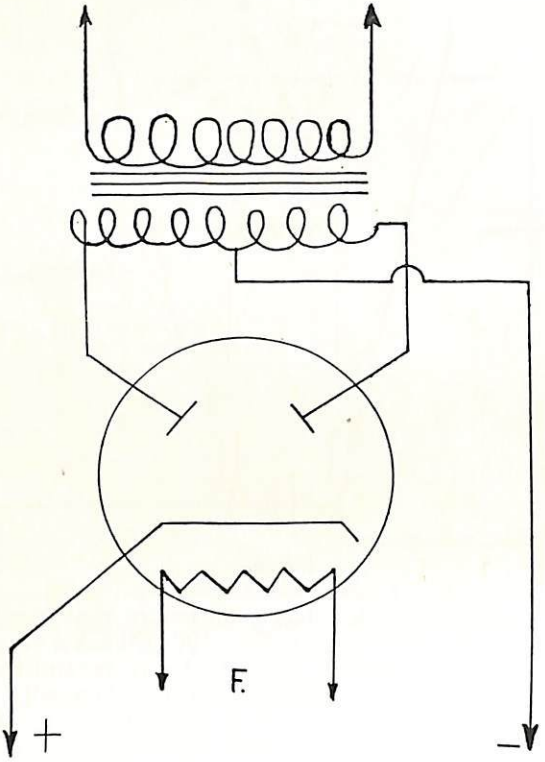



Fig. 6.

**The Thyratron.**

This is a mercury vapour grid controlled rectifier, in its most popular form, and is somewhat similar in principle to the mercury arc rectifier, with the exception that the latter has no control grid.

The pictorial representation of a valve, shown in Fig. 5, could represent a thyratron, providing it is borne in mind that the conduction media is mercury vapour and not a vacuum.

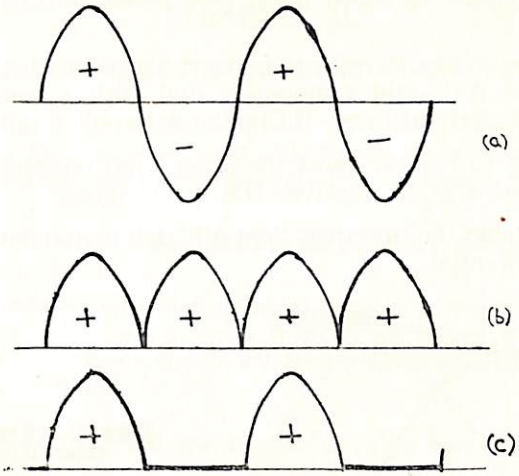



**Fig. 7.**

In a vacuum tube some of the electrons tend to gather near the cathode, creating a space charge, which tries to prevent the steady flow of electrons to the anode. When there is a metallic vapour inside the tube, some of the electrons collide with the vapour molecules, with sufficient kinetic energy to liberate electrons from the gas or vapour molecules.

When the gas or vapour particles are thus energised, they are said to be *ionized*; moreover the space charge becomes more positive and permits the release of more electrons. The current (*e.g.*, the electron flow) is then only limited by the actual cathode emission and the resistance of the external circuit.

Due to this ionization effect, the grid can only take over control of the tube current during the very brief period that the anode voltage is zero.

There are various ways in which the grid potential can be varied to find the tube at any point during the half cycle, but not once conduction has commenced.

There are two principal methods of grid control :—

(*a*) The method where the whole A.C. curve of grid voltage is "phase shifted" to the left or the right of the anode curve.

(*b*) The method where the A.C. grid potential is a constant value and is out of phase with the anode potential by approximately 90°, and then the A.C. grid curve is raised or lowered by the application of a D.C. potential.

It is intended to show, later, how phase shifting is brought about.

Reference to Fig. 8a will show the firing point of the thyratron with a fixed A.C. grid component, and with a constant phase displacement, but with zero D.C. potential applied (q.v.).

Reference to Fig. 8b shows the firing point retarded due to the application of a small negative D.C. grid voltage.

Fig. 8c shows the thyratron "cut off" due to maximum negative D.C. grid potential.

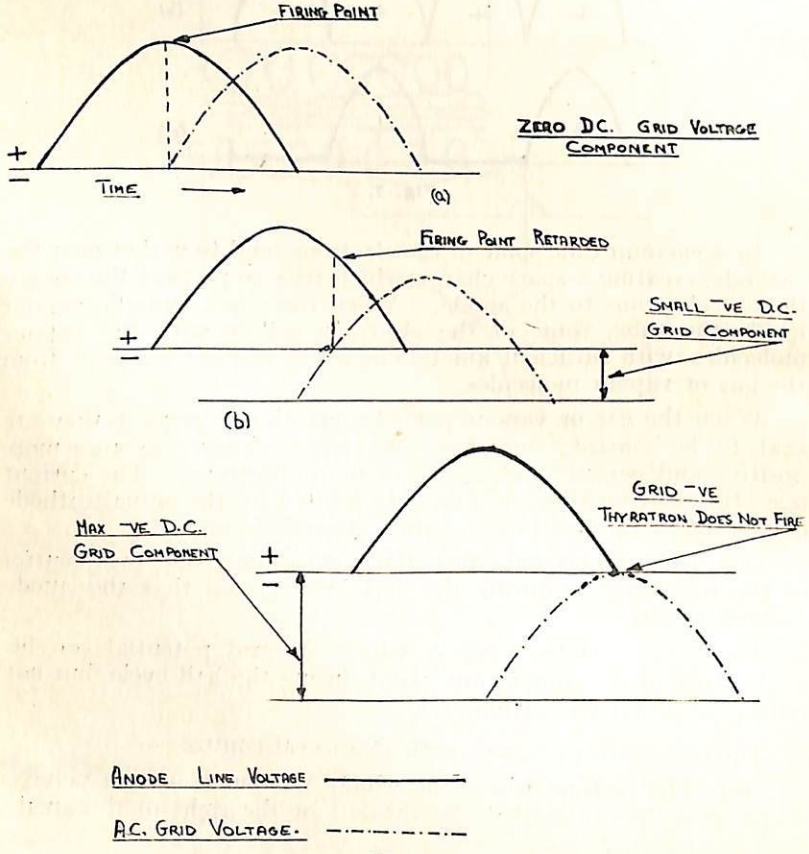



**Fig. 8.**

## CHAPTER II.

## VARIOUS EFFECTS OF ELECTRONIC TUBES.

In Chapter I. we discussed the behaviour of electrons through a valve or a tube, and we were able to get some idea of the comparatively simple control which could be obtained from a given electrode arrangement.

The thyratron was also introduced at this juncture, because of its general usefulness.

Before proceeding too far, we must obtain some idea of what major effects can be obtained from these tubes when used in different ways. These effects will be described under their relevant headings, as follows :—

(*a*) The principles of operation of a valve functioning as a :—

(i) Rectifier ... Diode.
(ii) Rectifier, ... Triode—grid controlled.
(iii) Amplifier, ... Triode-Tetrode-Pentode.
(iv) Generator, ... Oscillator or inverter.
(v) Controller, ... As a switch with time delay.
(vi) Transformer of *light* to *current*—photo-cell.
(vii) Transformer of *current* to *light*—cathode ray tube or indirectly as in an X-ray tube.

(*b*) The thyratron controlled by phase shifting—with P.S. networks. Approach to methods of phase shifting with inductance, capacity, resistance and saturated choke. Maintenance of pre-determined conditions with a double triode.

### Rectifiers.

We have seen that we are able to rectify alternating current to direct with static means by the medium of a thermionic valve and that if the valves used contain a suitable media (*i.e.*, mercury vapour) considerably larger D.C. currents may be drawn from the two D.C. points (*i.e.*, the cathode and the appropriate connection on the anode transformer) with thyratrons, used in pairs ; such rectification is termed bi-phase rectification. With the inclusion of a third electrode inside the glass envelope—geometrically situated between the cathode and the anode, we are able to control the average amount of D.C. voltage to a load circuit (*i.e.*, an armature or a field circuit). We have therefore a ready means of introducing further electronic control (*i.e.*, the employment of more valves) to make motor circuits automatic in operation.

Before investigating how the various controlling devices may be introduced it would be advisable at this juncture to discuss the functioning principles of thermionic valves and the effects that can be obtained from them.

With a simple diode—see Fig. 9, we can obtain *half-wave* uncontrolled pulsating D.C. and by the addition of another anode and suitable input circuit, *i.e.*, centre tapped transformer, we can obtain full-wave pulsating D.C. still uncontrolled.

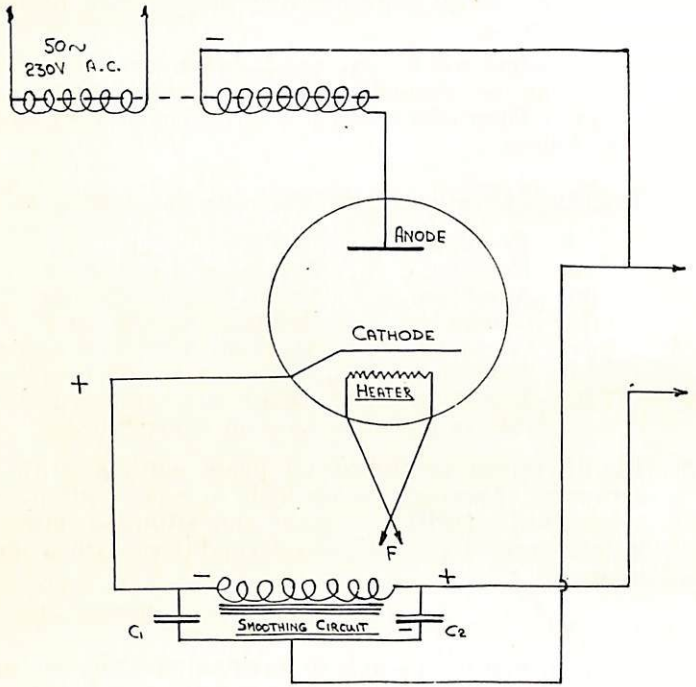



**Fig. 9.**

With the above arrangement we have what is termed a diode or double diode rectifier valve—this valve is usually a hard valve (*i.e.*, high vacuum for small current outputs such as those in radio work), but they can be produced as soft valves (*i.e.*, gas or mercury vapour), for larger output currents. With a third or fourth electrode we obtain a triode and tetrode rectifier, respectively.

This type of valve can therefore be used as a very efficient means of A.C. to D.C. conversion, and for purposes of reference call it effect No. 1, that is rectification.

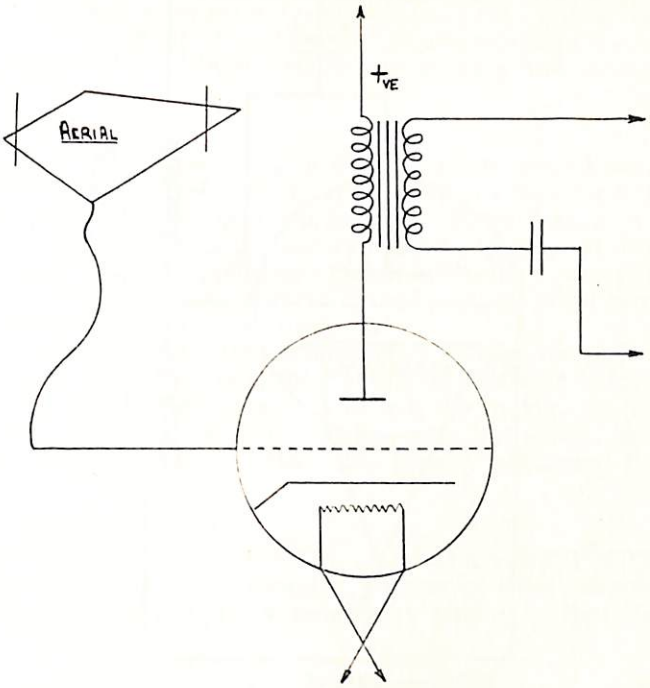



Fig. 10.

## Amplifier.

Reference to Fig. 10 will show us how a valve, in this case a triode, may be used as an amplifier. A very minute voltage applied to the grid can cause a much greater change of voltage or current in the primary winding of the anode transformer and the amplifier signal passed on to the grid of another stage of amplification if necessary.

Various circuit arrangements can be used for the purpose and it is not proposed to dwell on them here. More electrodes than are shown here can be used, but for our purpose it is only necessary to show that the valve can be used as an amplifier giving us what we call effect No. 2.

## Generator.

Reference to Fig. 11 will illustrate theoretically how a triode could be used for the generation of oscillations.

The valve is supplied with its voltages in the usual way, and the first impulse of current when switching the circuit into operation

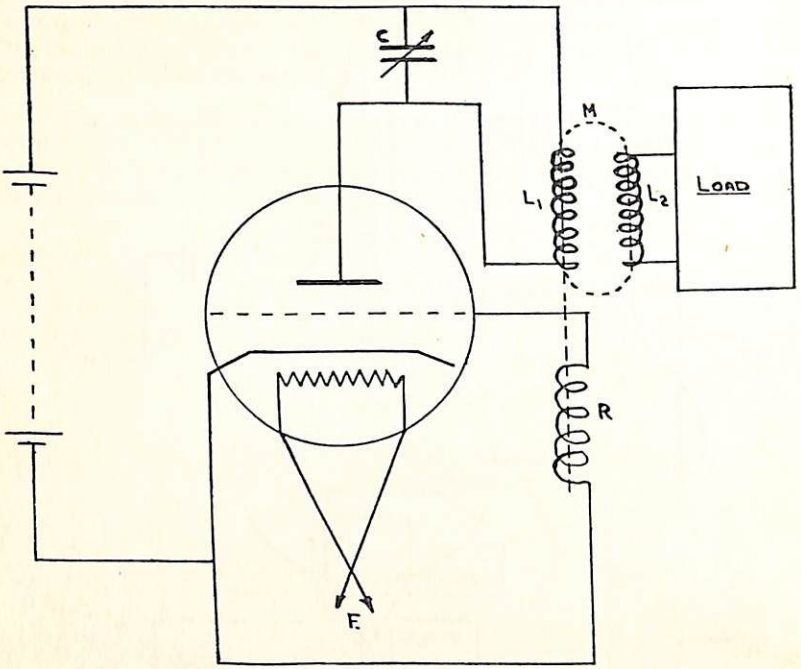



**Fig. 11.**

causes a swing of current, due to electron flow from the cathode to the anode, thence through the primary coil $L_1$ of the transformer back to the cathode.

The impulse in coil $L_1$ causes a corresponding impulse of current in coil $L_2$ which is directly connected to the load circuit.

Loosely coupled to the coils of the transformer is another coil R which feeds a signal back into the grid to produce another change of current flow through the valve, *i.e.*, an impulse, and this process goes on indefinitely until the circuit is opened.

The periodicity of oscillation, that is the frequency, is dependent upon the value of the variable condenser C and the fixed inductance of the circuit M whose inductance is usually referred to symbolically as L. The expression for the determination of the resonant frequency of the circuit is :—

$$F = \frac{1}{2\pi\sqrt{LC}} \text{ cycles per second.}$$

Where F = frequency in c.p.s.
L = inductance in Henries.
C = capacity in Microfarads.

We can see therefore that the valve can be used as an oscillator, an invertor (*i.e.*, a means of changing D.C. to A.C.) or a frequency changer (*i.e.*, changing the frequency of an A.C. circuit).

These effects will be put under one heading and termed effe No. 3.

**Controller.**

Because of the easy way in which we can control the flow of electrons through a valve by the application of a negative or positive signal voltage on the grid electrode, as shown earlier, it follows that we may use a valve as a very sensitive high-speed inertia-less switch and it can be applied as a circuit controller in many different ways. Very often such a valve is used as a gas filled relay when the conduction media is an inert gas.

It only requires a little imagination to realise the potentialities of a valve in this respect, the various applications being far too numerous to mention here. You will see in Fig. 12 that temperature, time and speed, to mention only but a few, can be the means of signal source to the valve thereby producing the effect No. 4.

**Time Delay.**

Before proceeding to the fifth effect of a valve it is important to discuss the valve as a controller, because by a very simple circuit arrangement we can use a time delay circuit so that the given

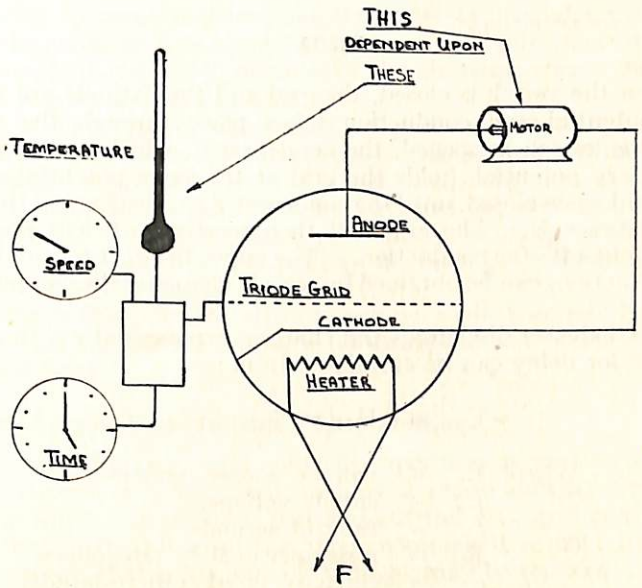
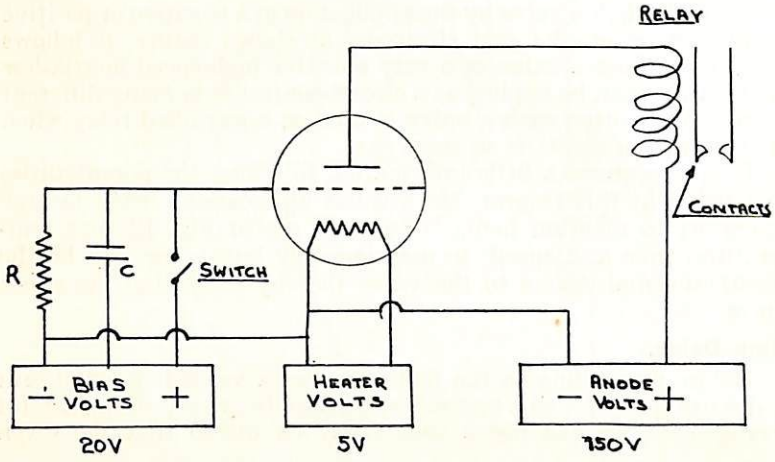



Fig. 12.

circuit conditions prevail for a pre-determined amount of time (*e.g.*, from milli-seconds to minutes), or alternatively we could delay the switching in of a circuit by the same method.

Referring to Fig. 13 you will see a simple triode valve which has a relay connected in its anode circuit. The grid signal source has a switch in series with it ; in parallel with the switch is a condenser and resistance.




From "Electronics in Industry."

**Fig. 13.**

When the switch is closed, the grid and the cathode are at the same potential and conduction takes place through the valve. When the switch is opened, the condenser C, which is charged to full battery potential, holds the grid at the same potential as the switch did when closed, until the condenser C has discharged through the resistance R. The grid will then receive sufficient negative bias to "cut-off" the conduction. The opposite effect (*i.e.*, delaying the conduction) can be obtained by merely changing the components about.

The condenser discharges and charges, exponentially ; therefore the time for delay can be calculated from :—

$$E_c = E_o \left( e^{-\frac{t}{Rc}} \right)$$

Where $E_c$ = voltage across condenser.
$E_o$ = circuit voltage.
$t$ = time in seconds.
R = resistance in M $\sim$ (Megohms).
$c$ = capacity in $u$F (Micro-farads).
$e$ = epsilon (base of naperian logarithms).

Although we did not propose to deal with any particular advantage in detail, at this point the value of this delay circuit is too important to be omitted, particularly as we are illustrating the valve as a controller.

**Light to Current.**

By the employment of a cold cathode valve of a special nature, we can obtain a fifth effect, that of transforming *light* to *current*. This special valve is known as a photo-electric cell.

When light strikes a half cylindrical electrode which is coated with a special metallic compound such as potassium or caesium oxide, electrons are released in proportion to the amount of light to which the electrode is exposed. There are several different types of this valve giving different susceptibilities to various parts of the spectrum, including the infra-red and ultra-violet.

This special type of valve can be used in conjunction with one or more of the other valves we have discussed, and the possibilities are, to say the least, very extensive.

Therefore, as previously stated, we have the effect which we term No. 5.

**Current to Light.**

It is to be expected, since all physical phenomena appears to be reversible, that current can be transformed into light. It would be as well to mention here that the ordinary incandescent lamp cannot be considered as a source of "current to light" phenomenon, since approximately 95% or more of the electrical energy supplied to such a lamp appears as heat.

One special type of valve used for the "current to light" conversion is the cathode ray tube ; the electronic flow within such a valve causes a specially treated screen (*i.e.*, tungstate of calcium or other chemical) to scintillate by virtue of the kinetic energy of the electrons. Another source of "current to light," though indirect, is the X-ray tube, but perhaps the most general and familiar case is that of the fluorescent lamp.

We have therefore the effect which we shall designate No. 6.

The various tubes, each with its own particular effect, will be discussed later.

**Gradual Approach to Variable Phase Shifting.**

With the thyratron grid controlled rectifiers as used in a motor control circuit, it is necessary to have a phase shifting circuit or network which will displace the phase of the A.C. grid component in relation to the phase of the anode component so that the armature voltage, that is the average voltage, may be reduced and give the desired method of speed control.

Referring back to Fig. 8 (*a*), (*b*) and (*c*), we can see what is meant by *grid voltage shifting*.

With the aid of Fig. 14 we shall proceed slowly to illustrate how *phase displacement* between the anode and grid voltages is brought about.

You will notice that we shall only be concerned with altering the grid phasing, leaving the anode phasing fixed. We could easily alter the phase of the grid by connecting a transformer between the grid and the cathode when only two possible conditions would be obtained :—

(*a*) The grid transformer would be of the same phase as the anode transformer, or

(*b*) The grid transformer would be 180° out of phase with the anode transformer.

In the case of (*a*) the effect would be the same as having no transformer in the grid circuit at all, and in the case of (b) the valve would not fire.

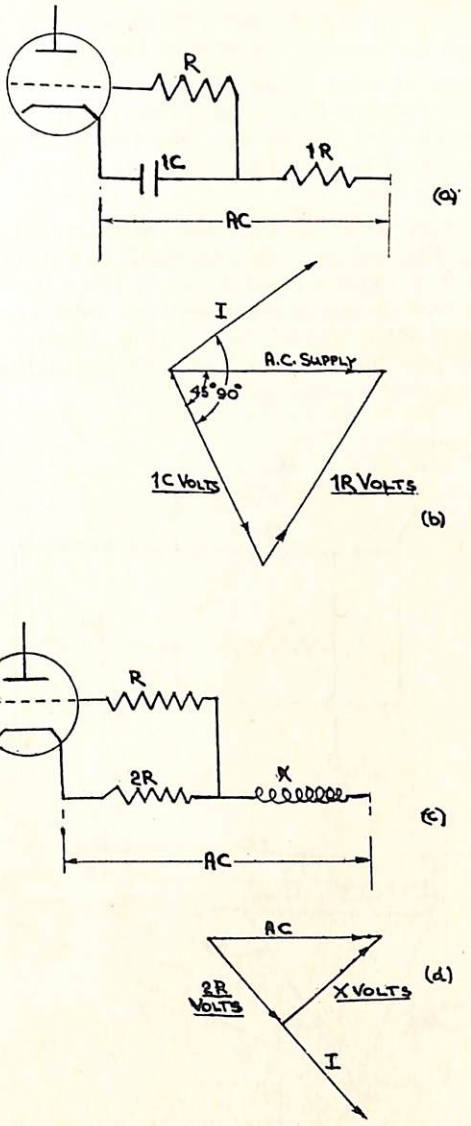
In Fig. 14a you will see a circuit arrangement using R resistance in series with the centre point of 1C and 1R, across which is connected the A.C. grid voltage. The resistance R is merely used to limit the grid current—you will remember that for grid control we require a little voltage with negligible current—and the condenser 1C and the resistance 1R give the vectorial result as shown in Fig. 14b. In this vector diagram the horizontal vector is the A.C. voltage supplied to the network. The vector marked I. is the current, the two outphased voltages, due to the effect of the condenser and resistance, are shown as 1C volts and 1R volts vectors respectively.

Therefore a voltage displaced by 45° is fed *via* the resistance R into the grid of the valve, but this phase displacement is definitely fixed at 45°, and for the particular circuit shown, it cannot be varied.

It is desirable at this stage to explain to those not familiar with A.C. circuits that when a pure capacity is connected to A.C. the current leads the voltage by 90°, and when a pure inductance is connected across a similar supply the current lags by 90°. If resistance is included in the circuit (in a practical case it always is present), then the angle of displacement between the voltage and current is always a value less than 90° dependent upon the values of the reactance of the condenser and inductance and the ohmic value of the resistance.

When the condensers and inductances are connected in parallel there is only one voltage and several currents, but when series connected there can be several voltages with only one current.

The resistance and condenser in Fig. 14a are series connected, hence the two displaced voltage vectors in Fig. 14b.




From "Electronics in Industry."

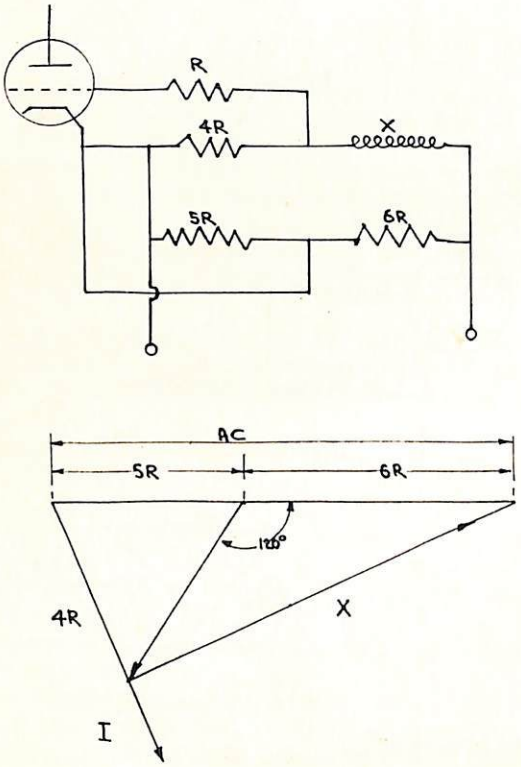
**Fig. 14.**

In Fig. 14c, the circuit is similar to that of (a) but an inductance is used instead of a capacitance (*i.e.*, a condenser).

The vector in (d) is also similar to (*b*) as far as the voltages are concerned, but the current vector is in the opposite direction.

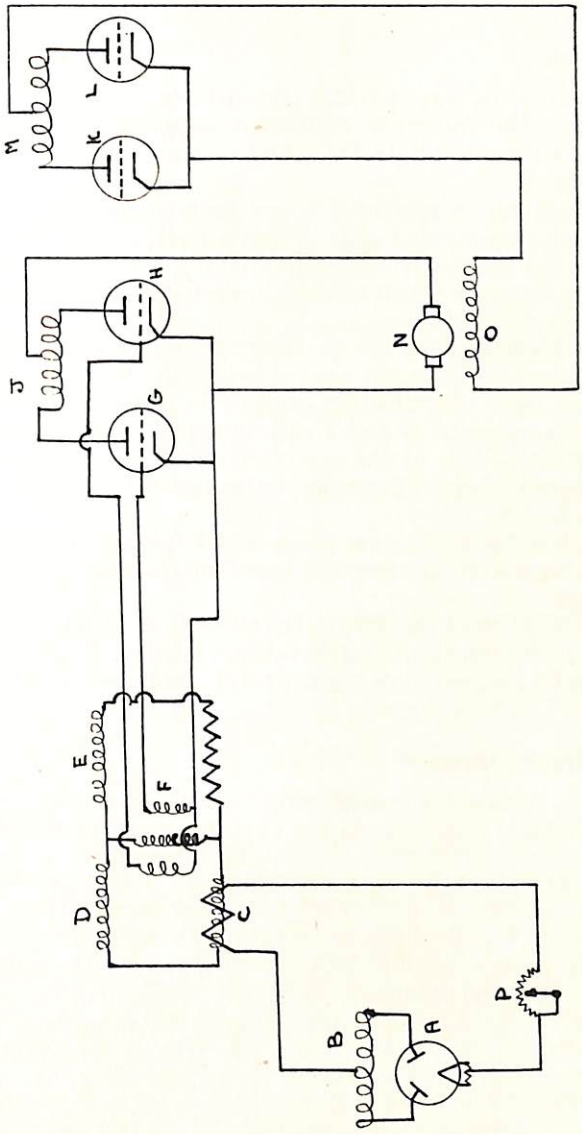
The current through a simple resistance circuit is always in phase with the voltage, that is why the current I. in (b) is parallel to the vector IR—(or should be ; the two vectors are only rough sketches), and in Fig. 14d the vector I. is superimposed on the resistance vector 2R.

We have seen, however, that the displacement due to the networks in Fig. 14a and 14c can only result in a displacement of 45°, consequently the valve cannot be fired later than the middle of half a cycle and is not satisfactory for most general cases, but might be useful for a special case. Fig. 15 shows a circuit very much like the previous network, but with the addition of two extra




From "Electronics in Industry."

**Fig. 15.**




From "Electronics in Industry," by George M. Chute.

**Fig. 16.**

resistances, and the theoretical vector in (b) illustrates that the phase displacement is now 120°—an improvement on that of Fig. 14a.

**Motor Control.**

Fig. 16 shows the way in which the variable phase shift network is connected. The full wave rectifier A supplies the transductor C (*q.v.*) with the appropriate D.C., and it can be varied with the potentiometer P.

The transductor or reactor C is one limb of the phase shifting network which is composed of D, E and a resistance ; the vertical winding between the two windings marked F is the primary winding of the grid transformer which controls thyratrons G and H to which armature N is connected.

The twin windings F are the secondary windings of the thyratron grid transformer, and the out phased grid voltage in the primary is induced into them to control the grids of the armature thyratrons.

The two cathodes of G and H are strapped together and constitute the positive side of the armature circuit, the negative side of the armature is derived from the centre tap of the anode centre-tapped transformer J.

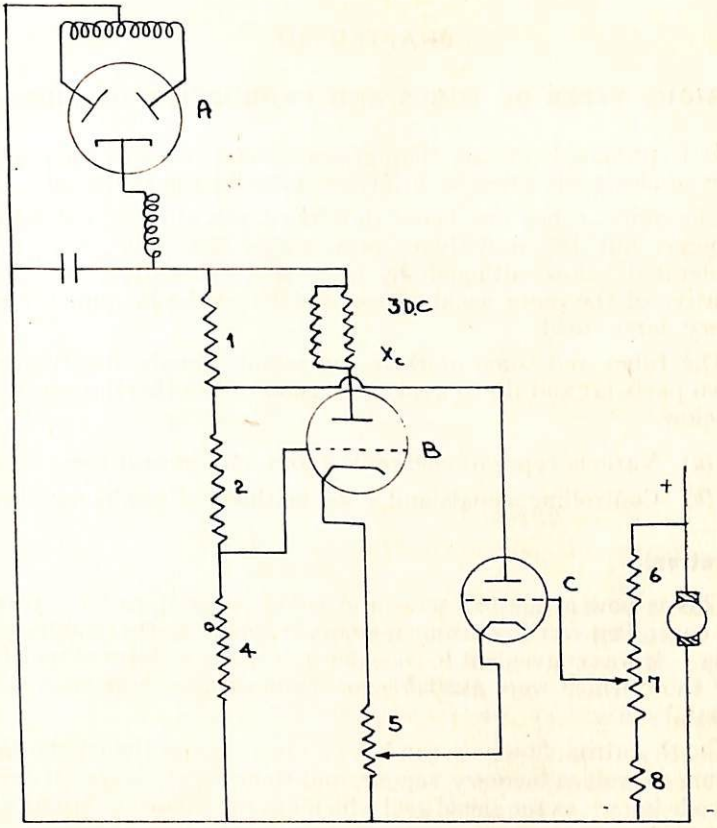
This bi-phase rectifier now gives a desired average value of armature voltage and controls the speed of the motor from zero to base speed.

The field winding of the motor, shown as O, is connected to the appropriate points on the twin thyratrons labelled K and L, and in this instance just supplies a steady D.C. voltage to the motor field.

**Simple Electronic "Brain."**

Some reflection on the operational principles of this system will show that unstable influences in the circuit (*e.g.*, voltage variation of the supply, or great change of loading on the motor) will produce very undesirable effects and for constant speed with variable loads some automatic control or "brain" is needed to watch for these disturbances and rectify them, instantaneously, as they occur.

Fig. 17 is a very simplified circuit to illustrate the action of the "brain," the staggered line Xc is the D.C. winding of the reactor C in Fig. 16 and tube A is the same rectifier as shown in that circuit. P has now become 5. B and C are two triodes (or could be a double triode) ; the triode C obtains its anode voltage *via* resistance 1, and its cathode is controlled by rheostat 5, which is in fact the speed control device on the front of the control panel of the motor. The grid C is controlled by rheostat 7 which is dependent upon the predetermined armature volts, and is set on the initial run and locked.




From "Electronics in Industry."

**Fig. 17.**

Triode B is in series with the D.C. winding of the transductor and controls the current through the latter. It has therefore taken the place of the potentiometer P in Fig. 16. Triode C is so arranged on initial setting that it "watches" the voltage across the armature voltage across the points 6 and 8, and if they differ from the pre-determined conditions set by rheostat 7, the valve alters the cathode voltage of triode B and alters the current through the winding Xc, to maintain the circuit condition as prescribed by the position of rheostat 5.

The response of this circuit is instantaneous. Thus, minor variations are not detected.

To avoid confusion all the circuit details have not been included in the foregoing.

## CHAPTER III.

## VARIOUS TYPES OF TUBES AND PRODUCTION OF SIGNALS.

It is proposed, in this chapter, to discuss the various popular types of electronic tubes with further notes on the thyratron.

Electronic tubes are being developed for all sorts of special purposes, but the underlying principle is the same, and those enumerated below, although by no means exhaustive, are representative of the more usual types, and as can be imagined, cover a very large field.

The tubes and some of their controlling signals are discussed in two parts (a) and (b) to avoid confusion. We therefore proceed as below.

(*a*) Various types of electronic tubes and general uses.

(*b*) Controlling signals and some methods of producing them.

### Thyratron.

This is now a familiar term and we consider it to be a triode grid controlled rectifier using mercury vapour as the conduction media. It was convenient to consider it only as one form of rectifier since those which were available for demonstration purposes were of that type.

The thyratron, however, can have an inert gas as the conduction medium as well as mercury vapour, and some valves have an extra electrode known as the shield grid which has the following functions:

(i) To reduce anode to grid capacity thus minimizing coupling between anode and grid with resultant reduction of loss due to anode voltage transients.

(ii) To shield the control grid from the anode thus reducing grid currents which might be caused by the deposition of cathode material on the grid, and by reducing the operating temperature of the control grid.

(iii) To modify the critical control grid characteristic by changes in the shield grid potential.

(iv) To effect dual control by the application of starting voltages to each grid. The starting of the tube can be controlled by the combination of two signals. A blocking voltage can be applied to either grid which would prevent starting of the tube, and upon the removal of this voltage, the tube could be controlled by a phase shifted voltage on the other.

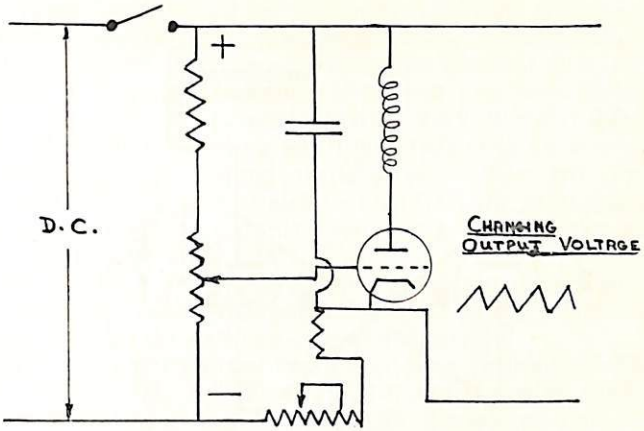



Fig. 18.

The thyratron can then be used as :—

(i) Rectifier—with positive or negative grid control.

(ii) Invertor—for conversion of D.C. to A.C. 1000 cycles or less can be generated. (See Fig. 18).

(iii) Frequency Changer.

(iv) Controller—in circuits with other electronic apparatus.

*The thyratron must always be vertically mounted.*

**Kenotron.**

This tube is a high vacuum rectifier designed to give a high D.C. voltage with little current. The voltages can be to the order of 20,000 volts and are used in electrostatic precipitators which are now being used to a very great extent.

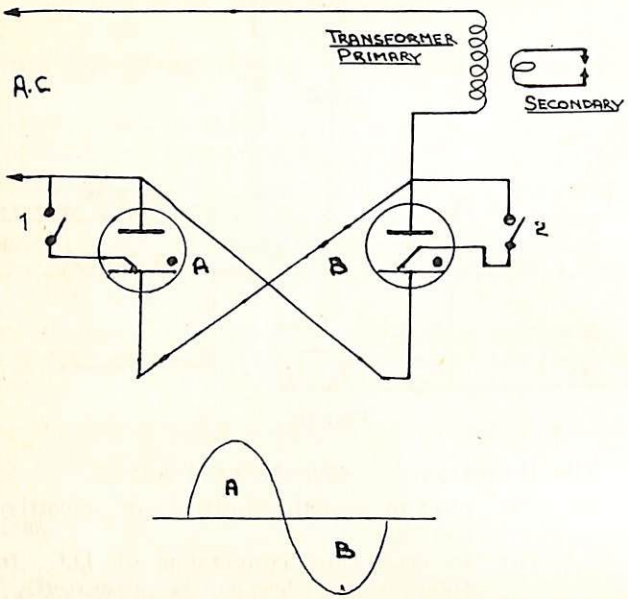
Due to the conduction medium (*i.e.*, high vacuum) the voltage drop at any appreciable current would be excessive.

They are eminently suitable in industrial and clinical applications.

The kenotron can be operated either vertically or horizontally. Particular attention must be paid to the installation of the tube because of the high voltages and possible radiation of X-rays from the tube itself.

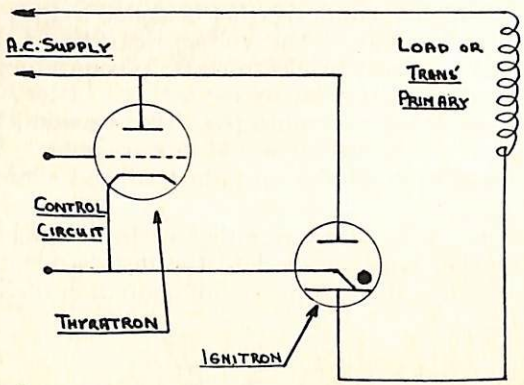
**Ignitron.**

This is a heavy duty mercury pool which controls very large D.C. currents at high efficiency.




From "Electronics in Industry."

**Fig. 19.**




From "Electronics in Industry."

**Fig. 20.**

The control is obtained by an ignitor electrode which projects into the cathode mercury pool and which, if supplied with a relatively small electric current, starts the conduction each cycle as required. The ignitron, once fired, can pass several hundred amperes and therefore is consequently very useful for welding control. Fig. 19 shows two ignitrons connected as heavy duty switch controlling a welding transformer. The two switches 1 and 2 control the ignitor, which in turn fires the tube and passes the current through the transformer for a large cyclic current operation such as welding, etc.

In Fig. 19 they are operating merely as circuit breakers and not as rectifiers, hence the reason for the crossed connections. (*i.e.*, anode of B to the cathode of A and *vice versa*).

Fig. 20 shows a thyratron being used as a switch replacing the switches shown as (1) and (2) in Fig. 19, and it can be easily seen that various control arrangements can be devised on such a basis, for instance, a synchronous controller for welding.

Because of the heavy currents which this tube can control it is sometimes water-cooled and special protective devices have to be introduced to avoid damage to the tube when used commercially, especially in automatic operations.

The foregoing tubes are made in various sizes each with its own special characteristics and reference to the appropriate data sheets is necessary when selecting one for a precise function.

**Cathode Ray Tube.**

This is a special form of electronic tube which when used in conjunction with other electronic tubes and circuits can perform many useful functions especially for the observation of transient phenomena.

The effect of the tube is demonstrated in Figs. 21 and 21a with a double trace on the screen, and it was possible to observe the bi-phase effect of thyratron rectification with the D.C. motor electronic gear.

Electrical and mechanical measurements of almost any description can be made on it, using of course, the relevant circuits.

The tube sizes vary according to the purpose for which they are designed—those for television purposes naturally being larger than those used purely for technical instrumentation purposes.

The tube is similar to a valve since it has a heater and cathode and electronic flow takes place from the latter through the vacuum or gas, whichever the case may be, to the anodes—note the plural term. These are sufficiently high potentials to accelerate the electron stream through them to the calcium tungstate (or other suitable chemical) screen, which, by virtue of their velocity, scintillate on the screen, and with the correct time base, appear as a trace.

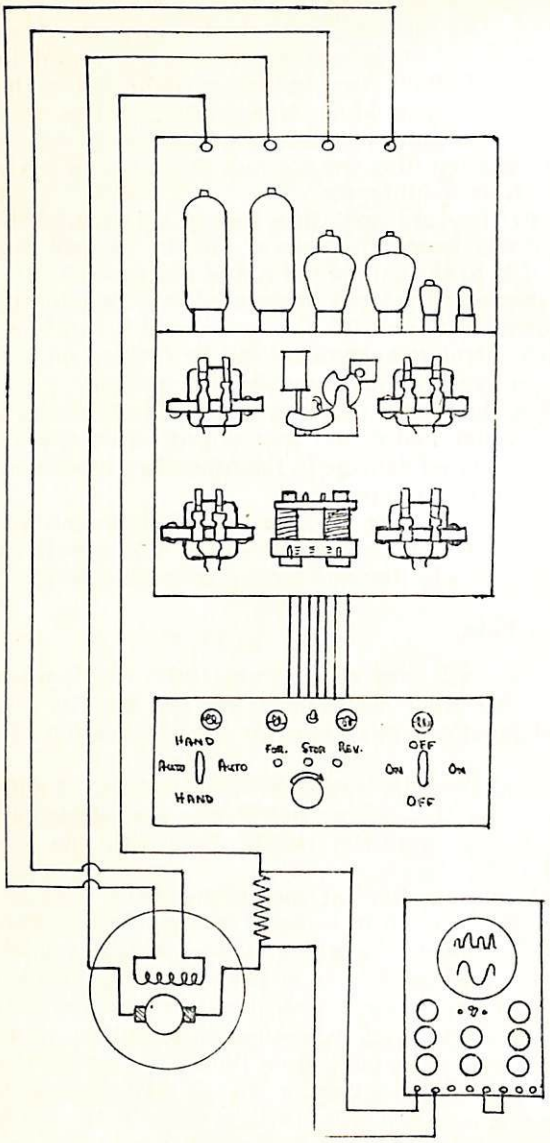



Fig. 21.

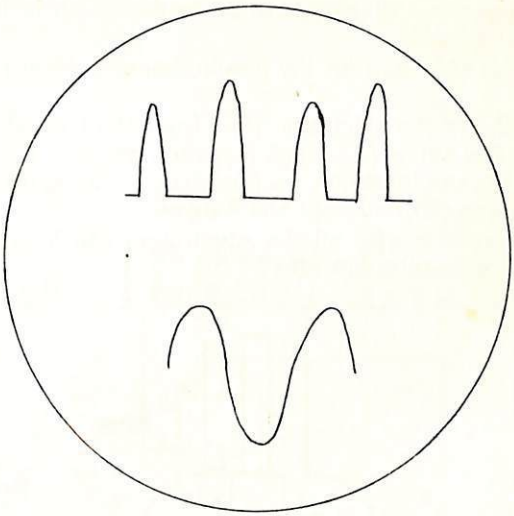


Fig. 21a

The various controls which you see are for the external control of the associated circuits which enable all the manifold effects to be interpreted into something tangible.

It is not possible to consider all the uses to which the cathode ray tube can be put, nor to consider the structure of the tube and the arrangement of its control circuits, but various types of valves are used with it to give all the effects which are possible when used as an instrument.

Cathode rays are sometimes produced expressly for the purpose of cathode ray radiation for biological reasons and then, although the tubes would be physically different in appearance, the principles of operation would be the same.

There is a small and simple version of the C.R. tube used as an indicator which is extremely useful in bridge and radio circuits—this may be, perhaps, more familiar to you as the magic eye tuning indicator.

Another useful application of the cathode ray tube is the cathautograph, which by virtue of its extended "afterglow" enables pictures of transmitted matter such as maps, specimens of handwriting, etc., to be retained on the screen long enough for a photographic record to be taken, thus simplifying facsimile production.

**X-Ray Tube.**

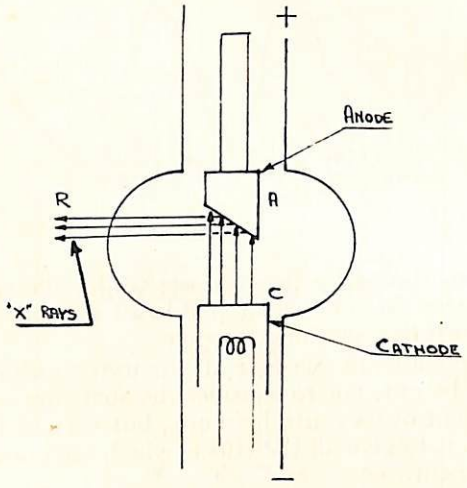
This is an electronic tube, which operates at an exceptionally high voltage (*e.g.*, several thousand to a million or more volts) and

enables analyses and diagnoses to be made, which hitherto would have been impossible.

The tube is also used for the production of gamma rays as with radium.

Fig. 22 shows the electronic flow from the cathode (C) which is heated, to the anode (A) which is maintained at a high potential, perhaps by the employment of a phanatron or a kenotron, and the resultant arrows (R) represent the X-rays.

You are familiar with all the advantages which this particular form of electronic tube can offer.




"X" RAY TUBE

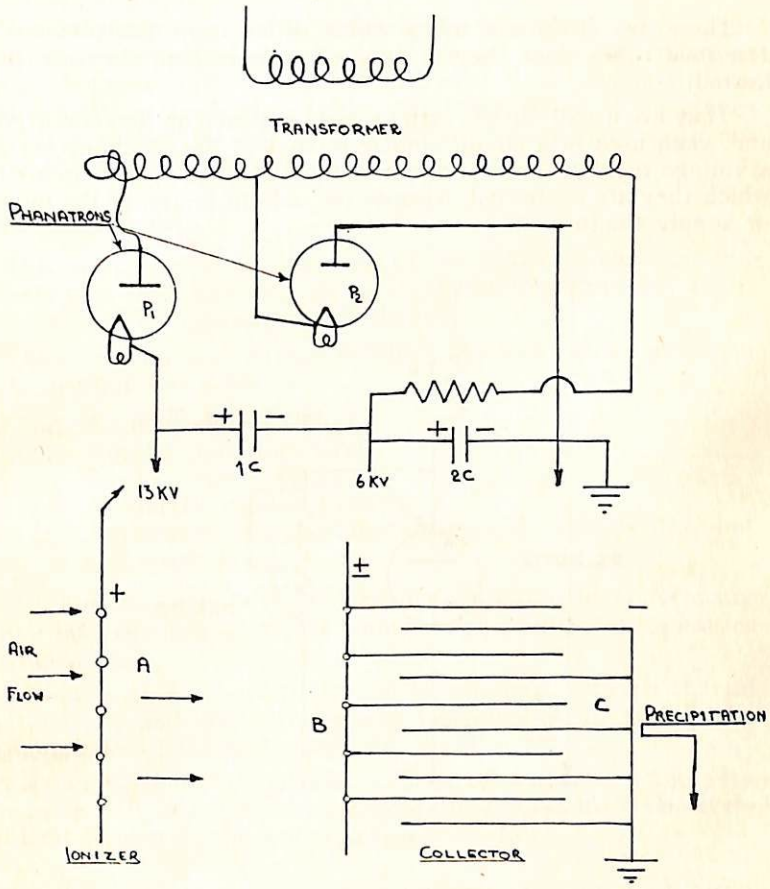
**Fig. 22.**

**Phanatron.**

These are medium current high voltage rectifiers using either a metallic vapour or an inert gas as the conduction medium. They are useful for power supply to radio systems and various industrial operations, such as precipitation, etc.

The metallic vapour version of the phanatron must be mounted vertically, like a thyratron, to keep condensed mercury at the lower end of the tube. The inert gas type, however, can be operated in any position.

Reference to Fig. 23 shows a precipitron voltage doubler circuit using phanatron tubes. The grid plates A are charged to a high positive potential say 13 kV. and the highly charged particles which have passed through the grid are subsequently attracted




PRECIPITRON VOLTAGE DOUBLER CIRCUIT

From "Electronics in Industry."

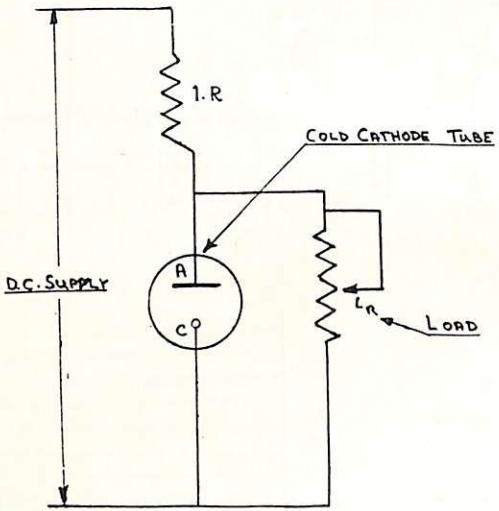
**Fig. 23.**

to the plates at B which are negative with respect to A. The particles at C are then finally precipitated to some suitable conveyor for disposal.

**Cold Cathode Tubes.**

These are electronic tubes which differ from the previously described tubes since they are non-thermionic (*i.e.*, they are unheated).

They are usually fitted with an inert gas such as Neon or Argon and when used in a circuit similar to that in Fig. 24, they act as a voltage regulator and maintain a fixed voltage in the circuit to which they are connected, irrespective, within limits, of the mains or supply fluctuation.




From "Electronics in Industry," by George M. Chute.

**Fig. 24.**

We obtain a steady voltage between points (4 and 2). Although the input voltage may vary as much as 20% the output voltage remains at its original value, the excess voltage being absorbed across the I.R. resistor.

The tube has a natural action to maintain the voltage, between its anode and cathode, at the value for which it was designed, and, since the current through the cold cathode tube increases with an increase in supply voltage, the excess voltage is developed across the series resistance rather than across the tube.

There are various forms of this cold cathode tube using different gases, such as the Neon or Argon glow lamp, each having its own particular characteristic.

They do not require a heater since conduction is effected by ionisation of the gas.

Several electrodes can be embodied in one glass envelope, the relevant connections being brought out so that the stabilized voltage between any pair can be utilized. One particular form of this multi-electrode tube is the stabilivolt, which is sometimes used in a similar manner to a potential divider, the regulation being about ·01 to ·02%.

**Photo Electric Cell.**

This is another electronic tube of the cold cathode type and consists of a sensitized cathode (*i.e.*, calcium or potassium) which when exposed to light rays emits electrons.

There are innumerable uses to which this tube can be put, such as, to mention but a few :—

(*a*) Sound tracks on films.
(*b*) Burglar and fire alarm.
(*c*) Smoke density meter.
(*d*) Automatic counting devices.
(*e*) Automatic control of machinery and various other not so apparent uses.

It is not always made in the form of a valve, but for convenience it may take the form of a very compact cell facilitating its use for instrumentation.

Several ranges of sensitivity can be obtained between that of the infra-red and the ultra-violet, depending upon the special characteristics of the particular tube or cell.

Certain versions of the photo-cell or tube can be made very responsive to light modulation, and it is possible to use a relatively dim light to operate the device in bright daylight.

**Pliotron.**

This term usually embraces all those hard vacuum thermionic tubes usually used as :—

(*a*) Modulators.
(*b*) Amplifiers.
(*c*) Oscillators.

They are similar in principle and construction to the ordinary radio valve used in audio-frequency circuits.

**Beam Power Tubes.**

This is a tube which has deflector plates connected to the cathode. These plates cause the electrons to converge as a beam on the anode and the "scattering" (q.v.) is minimized.

They are particularly useful as output valves and can be used for the excitation of small relays.

**Duplex Tubes.**

These are complex hard vacuum tubes and range from special triodes to multi-electrode versions such as octodes, etc. There are also special types such as secondary emitters. Secondary emitters use the "bounce" effect which we discussed earlier, the "bouncing" electron from the first anode is attracted to a second anode; this phenomenon can produce very useful effects in certain cases.

**Fluorescent Tube.**

This is not generally considered as an electron tube since it is most familiar as a source of illumination. It is the nearest approach yet to "cold light" and is very efficient since the greater part of its input energy is produced as light.

The ionization of the gas contained within the tube excites the fluorescent powder on the inside of the tube wall and scintillation occurs as in the case of the cathode ray tube screen, but the light emission is far more effective and pleasant than the ordinary incandescent lamp.

**On Producing Signals.**

In any electronic device the desired "effect" is naturally produced by a "cause" and this "cause" is usually termed the signal. We now propose to discuss the methods of producing these signals.

Signal sources can be obtained from the following causes :—

(*a*) Sound through various frequency ranges.
(*b*) Light—in all parts of the spectrum.
(*c*) Heat—in all parts of the temperature range.
(*d*) Electro-static and electro-magnetic changes in various forms.
(*e*) Electrolysis.

(*d*) and (*c*) are generally considered as electrical changes and are produced by the following :—

(1) Resistance variations.
(2) Inductance variations.
(3) Capacitance variations.

Mechanical changes constitute a signal source when converted into electrical signals by introducing (i), (ii) or (iii).

Resistance signal sources can be obtained from the effect of light, heat and sound by :—

(i) Selenium Cell, ... ... Light.
(ii) Bridge Thermometer, ... Heat.
(iii) Microphone (Carbon), ... Sound.

**Self Generation.**

With the exception of tachometer and selenium cell the above sources require a voltage input for excitation, but various methods of self-generated signals may be used such as :—

Heating a junction of two dissimilar metals which produces a very small voltage which can be amplified according to requirements.

Apparatus operating on this principle is called a pyrometer.

Another phenomena convenient for self generation is that of crystal compression which derives its voltage from the faces of crystal plates specially cut for the purpose.

The term "self generation" is understood to be in the electrical sense only since the physical properties of a device to be controlled supplies, or is the means of bringing about, the energy for the resultant signal. For instance, sound waves could inpinge on the diaphragm of a moving coil microphone and a voltage produced according to the frequency and amplitude of the sound waves—the sound waves supply the requisite energy.

Electrolytic action could also be another self generating source of signal.

With capacity inductance and resistance coupled with the effects of temperature, humidity, pressure, viscosity, speed, time and weight, etc., innumerable different methods of signal generation can be obtained and used for every conceivable means of registration and control.

Tachometers are small generators which when mechanically connected to the driven apparatus produce electrical impulses either A.C. or D.C. proportional to the rate or propulsion of the driven apparatus.

The signal can then be used both for registration of the rate of propulsion and as a means of signal injection to control the apparatus as necessary.

For instance, the tachometer signal could be fed into the control grid of a thyratron which in turn could operate some other device such as a relay or a transductor. Some thought will no doubt suggest many other applications even for this limited signal source.

Other sources of electro-magnetic variation for the purposes of signal injection are :—

(*a*) Transductor—Saturable choke. (See Chapter 4).
(*b*) Variable Choke or Reactor.
(*c*) Peaking Transformer. (See Chapter 4).

The variable choke usually comprises a winding with an adjust able laminated iron core.

Mechanical initiation or changes can be converted into the necessary electrical impulse with either (*a*) or (*b*), and the impulse injected into the appropriate control circuit.

Similar mechanisms can also produce electro-static signals by the variation of capacity, an instance being quality control of materials which are processed on a continuous conveyor system—the actual material can constitute the di-electric of a condenser with a known permittivity for acceptable production tolerances, any variations in the permittivity of the material changes the capacity.

Inductance and resistance variations would also produce the signals from the same mechanical variations and can also supplement the capacity effect.

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## CHAPTER IV.

## SPECIAL NON-ELECTRONIC AND ELECTRO-MAGNETIC DEVICES.

Due to the very rapid response rates of electronic circuits and the broad range of ingenious circuits which can be utilised to perform what may appear to be almost impossible functions, it is necessary to have special electro-magnetic equipment designed for particular use with it.

Conversely, special electro-magnetic machinery and apparatus may be made to operate more efficiently by electronic means. It is therefore desirable to describe some of these non-electronic but complementary devices.

### Special Electro-Magnetic Devices.

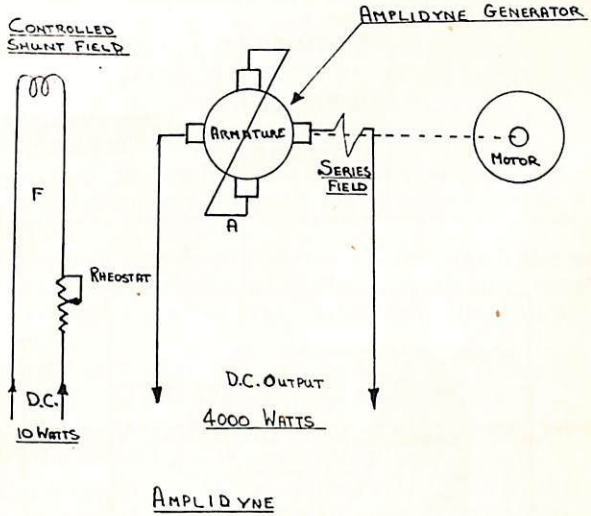
There are two rather special cases of electro-magnetic signal source, either as receivers or transmitters, that are worthy of mention :—

(*a*) The Amplidyne.
(*b*) The Selsyn.

The amplidyne system is an amplification system of generator or motor field current in which a small current of a few milli-amps can control very large generated or absorbed currents (*i.e.*, 10 watts can control several thousand watts of power).

The sketch in Fig. 25 briefly illustrates the idea upon which it is based ; the excitation shunt field is shown at F, the armature at A, the series field at S and the driving motor M.

The field F is energised by a very small D.C. supply and this D.C. is amplified by the armature current through the short-circuited section shown, and a large but easily controllable output is obtained.




From "Electronics in Industry."

**Fig. 25.**

The armature is similar to that of an ordinary D.C. machine and is usually a two pole machine, but the field winding is distributed in slots. When four brushes are used two are short circuited, and the actual operation is similar to that of a D.C. motor generator set, but the response rate is much faster.

The small field winding occupies very little space in the frame of the machine, consequently several fields of a like nature can be used inside the same framework for external control (*i.e.*, voltage, regulation, speed regulation, anti-hunting).

The external control could comprise either, or both, electromagnetic or electronic means.

There is one particular case where a transformer can be used on D.C. for the prevention of hunting. This may seem odd, since transformers are usually only associated with A.C. equipment.

Suppose the primary side of a transformer to be connected to the output side of an amplidyne generator, and the secondary side to be connected to an extra field winding in the field system of the generator (this field coil is known as a "bucking" coil). When the output voltage is constant, there is no rate of change on the primary side of the transformer ; therefore the secondary "impulse" is nil, but if there is a momentary change on the primary, due to unstable conditions on the output circuit of generator, this change results in an impulse being injected into the "bucking" coil and damps down the instability.

The selsyns, see Fig. 26, are electro-magnetic units used for remote indicator or control of dependent movement.

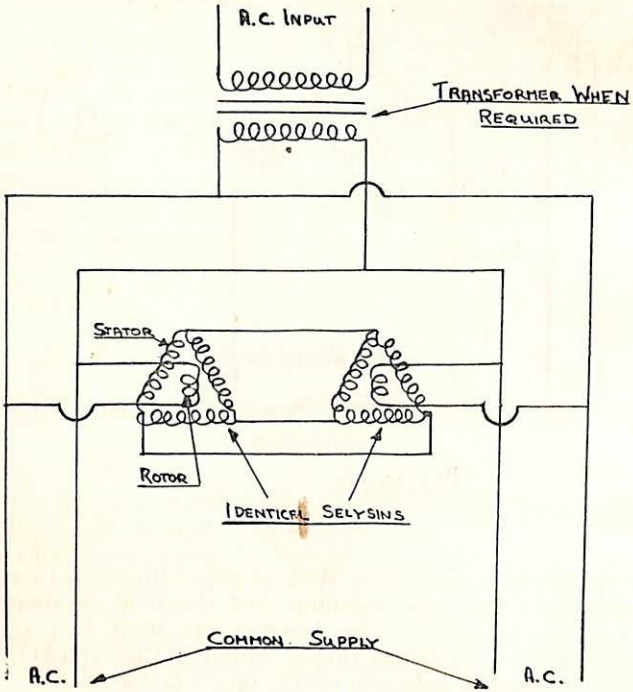



Fig. 26.

If pointers are properly mounted on each of the selsyn shafts and the pointer of one is rotated to a certain position on a suitably calibrated dial situated behind the pointer, the other selsyn pointer will move, in synchronism, to an identical position on its corresponding dial. For purposes of remote indication the selsyns are very small units, and they can be designed for A.C. and D.C. operation.

Power selsyns can be used on a three phase system, and they act like wound rotor (slip-ring) induction motors.

When, for instance, a motor is driving a selsyn at 1000 r.p.m., another selsyn, electrically connected, will run at exactly the same speed, the first selsyn acting as a generator ; the two units being in synchronism.

Suppose that a 10 h.p. selsyn is mechanically coupled to a 10 h.p. motor driving a load, while a duplicate set is connected electrically and is driving another load, then neither selsyn does any work as long as both driving motors revolve at the same speed. Should the second motor, however, attempt to turn at a slower speed, the second selsyn naturally lags behind the first, and this second selsyn acts as a motor and draws energy from the supply. This decreases the load on the second motor, but increases the load on the first motor so that they both turn at the same speed.

**The Peaking Transformer.**

This is an ordinary double wound transformer, with the exception that its special iron core contains much less iron than the more orthodox type.

The amount of iron in the section around which the secondary is wound is much less than that of the primary core, consequently the sedondary iron core becomes "saturated," preventing the flux from changing.

This results in a peak wave form in the secondary, whilst the wave form of the primary is the usual sine wave.

When used with a series resistance the peaks can be arranged to occur at the desired position on a time base.

It is also necessary to include a resonance filter in the primary, comprising a capacitor and reactor to prevent unwanted peaks.

These peaking transformers are therefore very useful for resistance welding heat control.

**The Transductor (or Saturable Reactor).**

This is a variable inductance, sometimes termed a choke, and similar in appearance to a transformer since it has two windings one of which is used for A.C. and the other for D.C. The D.C. winding is used for "saturating" the core from a D.C. source, either externally or by feed back from the A.C. input.

Since the inductance of a choke or reactor depends upon the magnetic flux density in the core, it will be appreciated that it is comparatively simple to vary the D.C. component on the transductor, resulting in a very much larger change in the A.C. component. When we increase the amount of current in the D.C. winding, the current through the A.C. winding increases.

It would be as well at this juncture to consider an ordinary choke, the physical examination of which would reveal that it is composed of a laminated iron core, around which are wound several turns of insulated wire.

These turns produce the magnetic flux within the core, and for a given set of conditions the inductance is fixed ; the current then passed by the choke is determined by the reactance X of the choke circuit. The total impedance Z of the unit is the vector sum of the reactance $X_L$ and the resistance R.

Thus $Z = \sqrt{R^2 + X_L^2} = \sqrt{R^2 + (2\pi fL)^2}$
Where L = inductance in Henries due to its magnetic flux.
and $f$ = frequency of A.C. supply in C.P.S.

Now if another winding is introduced on to this core in such a way that no voltage from the existing winding is induced into it, and this winding is supplied with a D.C. voltage to permit a very small current flow (*i.e.*, a few milli-amperes) the saturation of the core can be controlled by a small rheostat in series with the D.C. supply.

The possible combinations of network, as can well be imagined, are manifold, but where variable control is essential, some of them would be impracticable.

The variable reactor, then, is a very convenient means of obtaining variation of an A.C. component in a phase shifting network, or any circuit where infinitely smooth control of A.C. is required.

With a suitable arrangement the transductor can be used as a magnetic amplifier, since by the use of the feed back, hitherto mentioned, a small signal current can be amplified several thousand times.

Coupled with the appropriate electronic circuits and other electro-magnetic apparatus, the field of application of the transductor is very large.

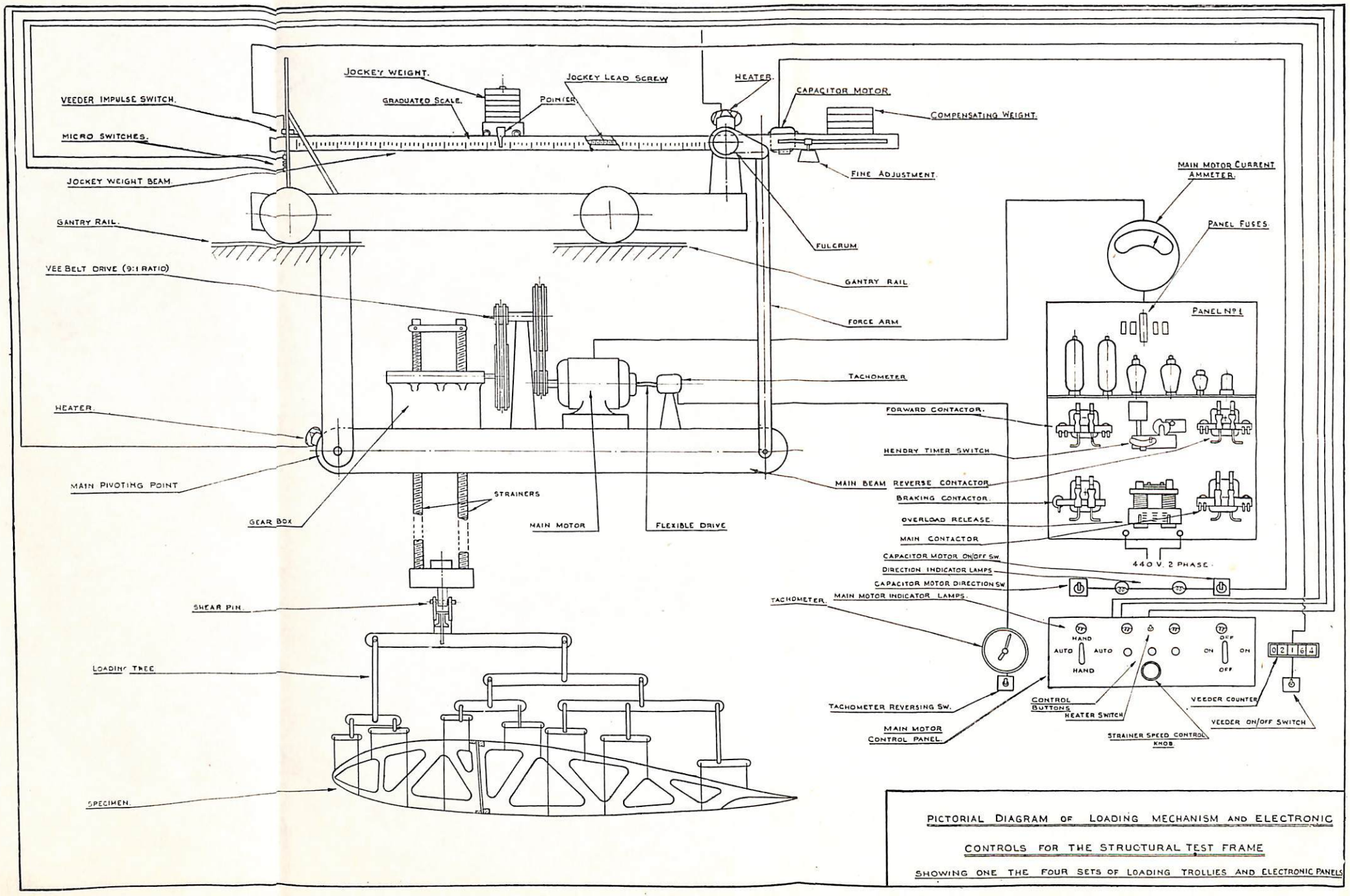
**Special Resistances.**

There are two types of resistance that warrant special reference. They are :—

(*a*) Non-ohmic resistors.
(*b*) Thermistors.

Non-ohmic resistors are made of silicon carbide baked at a very high temperature. The surfaces are specially treated to render them suitable for contact purposes.

The action of this type of resistor is rather peculiar. When you increase the voltage across an ordinary resistor the current increases in direct proportion to the voltage increase and thereby responds according to Ohms Law, but when the voltage across a non-ohmic




PICTORIAL DIAGRAM OF LOADING MECHANISM AND ELECTRONIC CONTROLS FOR THE STRUCTURAL TEST FRAME SHOWING ONE THE FOUR SETS OF LOADING TROLLIES AND ELECTRONIC PANELS

**Fig. 27.**

resistor is increased beyond a certain limit, the current increases out of all proportion to the increase of voltage ; in fact it increases by about 10 or 11 times the amount of an orthodox resistor.

This effect is particularly useful, for example, in a circuit which must be protected from high voltage surges, because when the surge has diminished the electrical characteristics return to normal (*i.e.*, lightning conductors, etc.).

Thermistors are specially made resistors, which by virtue of their large negative temperature co-efficient are very responsive to comparatively small changes of temperature. Consequently they are particularly suitable for bridge thermometers.

The resistors when used in an appropriate circuit can sometimes be the means of overcoming, quite simply, what appear to be insuperable difficulties.

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## CHAPTER V.

## ELECTRICALLY CONTROLLED STRUCTURAL TEST FRAME.

Reference to the pictorial representation in Fig. 27 will indicate the principles upon which the straining mechanism of an aircraft structural test frame operates.

The equipment shown in the illustration is one set of four complete electronic and mechanical units which are operated on large steel structures, the dimensions of which are approximately $60' \times 20' \times 20'$, and the loading capacity of the whole frame is 40 tons.

The illustration shows an end elevation view of a specimen wing, to which are connected several hundred resistance strain gauges, so that the strains at any pre-selected point on the specimen, at given loadings, can be observed and subsequently recorded.

An electronic automatic strain gauge recorder is employed, which enables 600 readings to be recorded in a few seconds.

The strain gauge is based on the principle that a small incremental increase in tension causes a corresponding incremental increase in the resistance of the strain gauge, and with compression the resistance is decreased.

Therefore, if the small resistance changes are amplified and observed on an oscilloscope which serves as a monitor, and another oscilloscope is recording the same signal and being filmed by a cine camera, we have a very fast means of observing and recording the behaviour of the wing structure under test ; that is the function of the 600-way strain gauge recorder.

Another example of the use of an electronic technique in this case was the calibration of the straining mechanism by an electronic weighing unit. The equipment can be carried about in a suit case and taken to any aircraft for immediate weighing facilities. The accuracy is to the order of $\pm \cdot 5\%$ and if it fails, it fails safe.

The apparatus comprises three weighing cells, which in effect are blocks of steel with strain gauges bonded on to the four sides, and an oscillator and amplifier circuit. The gauges are part of a bridge network, complete with the necessary drift and temperature compensating circuits. The sensitivity is so good that, although each cell has a weighing capacity of 50,000 lbs., the pressure of one finger on the cell can give a discernible reading.

Referring again to Fig. 27, it can be seen that there is a "family tree" system of mechanical linkages to distribute the load at the desired parts of the particular station. This illustration shows only one loading station : in this case, however (*i.e.*, wing test) there are three others.

The wing, when under load, will deflect much more at the tip than at the root end, so that each screw jack will have a rate of travel proportional to the deflection of the main plane being at its particular station.

This process of straining continues until the specimen is eventually destroyed.

The remainder of this chapter is devoted to a description of the electronic control gear and its functioning, and is dealt with in the following sequence :—

(*a*) Motors and their function and general arrangement of the electronic panels.

(*b*) The main functions of the controlling devices, comprising :

- (i) Thyratrons and control valves.
- (ii) Hendry time delay mechanism.
- (iii) Interlocking contactors and associated equipment, including remote control.
- (iv) Stepless speed and operational control of motor.
- (v) Characteristics at various H.P. and torque valves.
- (vi) Advantages of the use of electronics in this case.

(*c*) Principle of thyratron operation with wave forms shown on oscilloscope.

It can be seen from Fig. 28, which is a schematic diagram of the loading mechanism, that the main motor which is a D.C. machine drives the screw jack mechanism which is connected to the main beam of the test rig structure and through a linkage system to the jockey-weight balance arm. The jockey-weight balance arm is controlled by a small A.C. capacitor motor which runs at a uniform

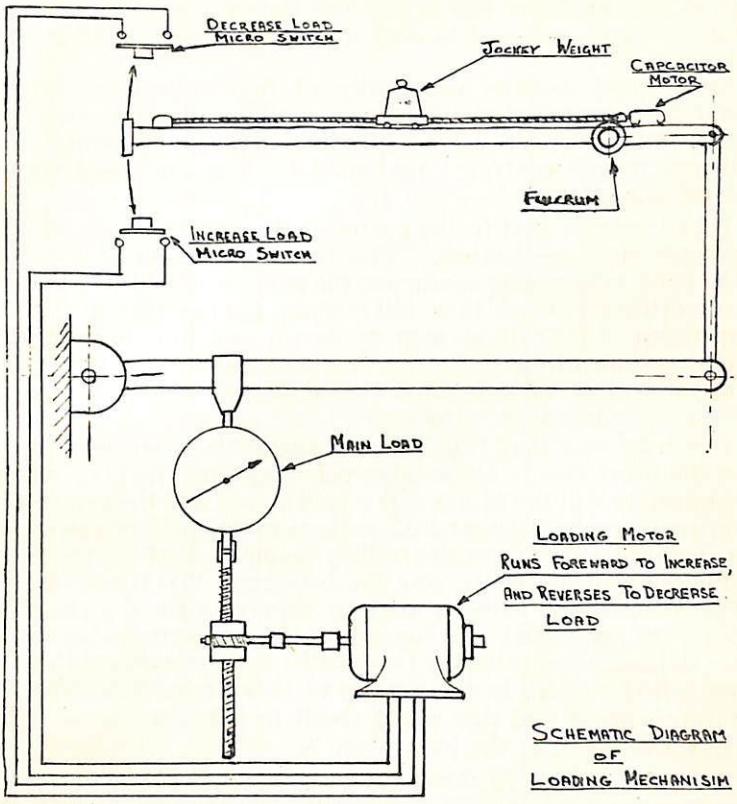


**Fig. 28.**

speed of 4½ R.P.M. This arm is calibrated with a uniform scale into 10 major units, so that the jockey-weight can be driven by the small A.C. motor to a pre-determined switch position, which will be at a pre-arranged point on the jockey-weight balance arm.

The ratio of the jockey-arm loading to the main beam loading is so arranged that a weight of 240 lbs. on the former at its maximum distance along the jockey-weight arm balances a load of 10 tons on the main beam, on which is situated the main screw mechanism. The main screw jack mechanism as hitherto mentioned is driven by a D.C. shunt wound motor, which has series characteristics, since it is controlled by the electronic panel which you can see depicted in Fig. 27. This electronic control panel, of which there are four complete sets in all, controls the D.C. screw jack motor. The control of speed is from crawling speed to the rated base speed of the motor, and the panel is so wired and arranged

that the motors can be run in one direction, rheostatically braked, and immediately reversed to give either an increase or decrease of load.

Each panel consists principally of four thyratron mercury vapour grid controlled rectifiers, one rectifier valve full wave, one double triode control valve, and interlocking contactors, with local and remote control; the small knob is the speed control rheostat (*q.v.*).

It can be seen that in the centre of the panel there is situated an electric clock mechanism. This mechanism gives a time delay to the main interlocking contactor, the purpose of which is to allow the thyratrons to reach their full working temperature so that the temperature of the cathode is at its correct value for emission when current is drawn from it, and furthermore this temperature has to be at the correct value to allow the condensed mercury inside the valve to be adequately vapourised.

It can be seen that two of the thyratrons are somewhat larger than the other two. These large valves control the D.C. voltage to the armature of the 1½ h.p. screw jack motor, and the two smaller thyratrons supply constant D.C. voltage to the field of the motor. The double triode is the controlling medium, that is, the phase shifting network for controlling the two larger thyratrons and the full-wave rectifying valve is used for supplying the double triode with its D.C. potential. We could by the application of a similar phase shifting network to the two smaller thyratrons vary the field current of the motor in the same way as we have done with the armature current and this would result in a greater speed of the motor up to 300% of the base speed.

Reference to Fig. 29 shows the torque and H.P. characteristics of a similar motor as we are using on the straining mechanism, but with armature control and field control, and it can be seen that with armature control only, as the bottom half of the diagram shows, that from zero to base speed the torque is constant but the H.P. variation is proportional to the speed; in the upper half of the diagram, that is using field control, the H.P. is constant but the torque does not vary in direct proportion to the speed, but takes the form shown.

In the case of the screw jack motors used in this test frame, we are keeping the field at constant voltage, and only varying the armature by the method of phase shift on the large thyratron grids.

If we refer to Panel No. 2 illustrated in Fig. 21, we will see that we have a separate D.C. motor connected to it for convenience, since it is difficult to imagine the actual motors situated on the test rig. Connected to this motor is an oscilloscope with which we shall demonstrate the change of wave form due to the rectification of the thyratrons when supplying the armature current. This is shown now on the oscilloscope screen, Fig. 21a. The bottom

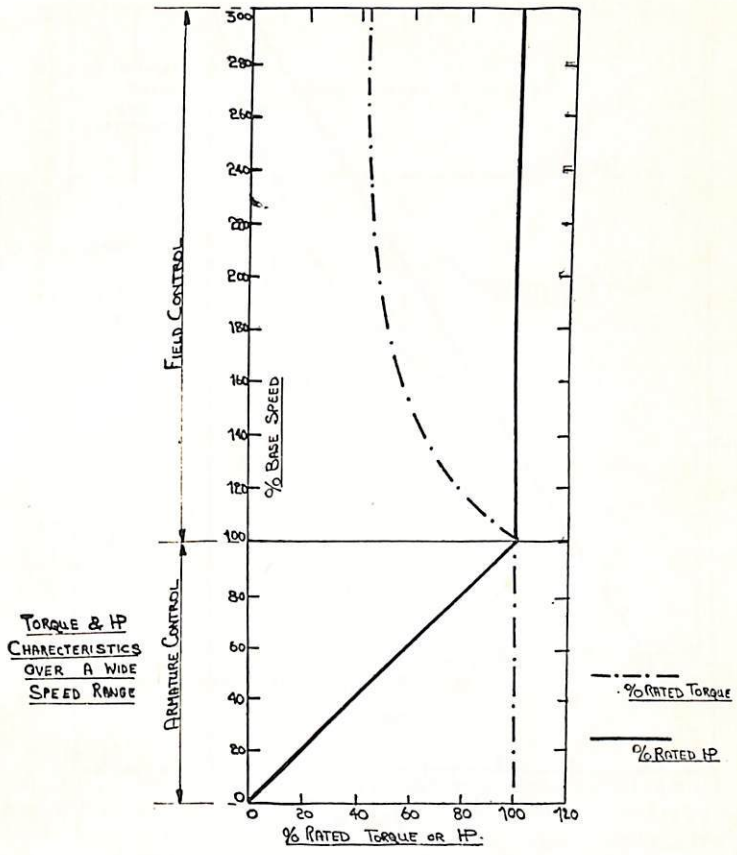


**Fig. 29.**

half trace "A" shows the sine-wave current on the anode of the thyratron valves, and trace "B" shows the rectified A.C. current, which, is, in fact, pulsating D.C. current passing through the armature of the motor. The difference in amplitude of the two half-wave traces is due to the slight difference in the conductivity of the thyratrons whilst the motor is running on no load. It can be seen that by a variation of the speed control rheostat the motor accelerates uniformly and decelerates likewise since this rheostat is part of the phase shifting network to which we have previously referred, but not in detail.

Referring now to Fig. 30 the dotted line in the upper part of the diagram indicates the base speed position. The thick stepped line in the same portion of the diagram illustrates the variation of

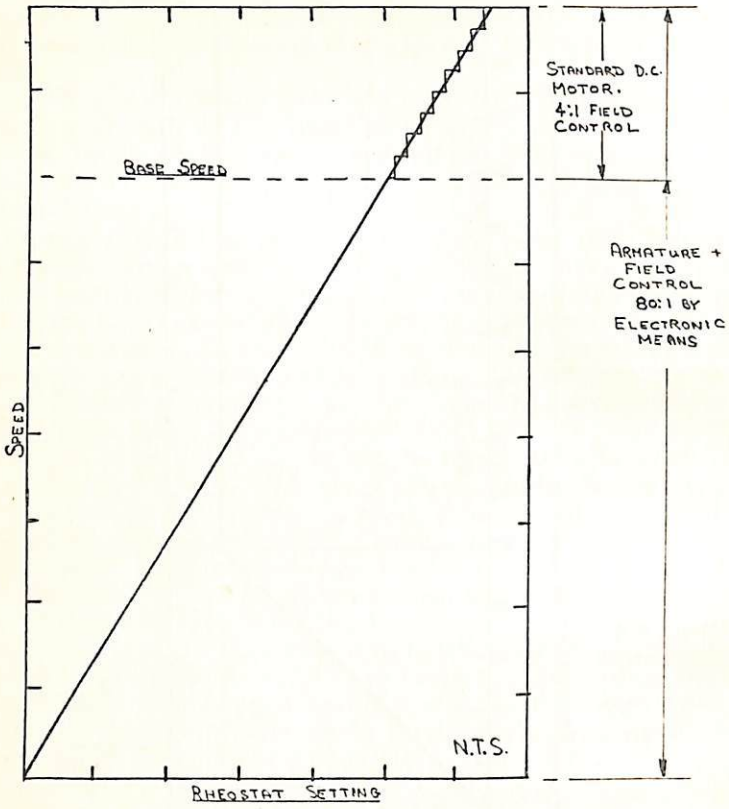


**Fig. 30.**

speed, in relation to rheostat setting of a standard D.C. motor with a 4 - 1 ratio field control.

The over-all picture shows an armature plus field control which is 80 - 1 by electronic means.

Fig. 31 merely illustrates the H.P. and torque characteristics of a D.C. motor in relation to the base speed, the curved line showing the torque when the H.P. is constant and the diagonal line the H.P. when the torque is constant.

The elementary diagram in Fig. 28 will demonstrate the fundamental principle of operation of No. 1 electronic control gear and the strain mechanism by using a 600 lb. range spring balance which is connected by steel cable from a beam at ground level to the fixing point on the end of the screw jack.

Suppose that we now switch on a capacitor motor and switch to "auto" on the electronic control panel so that the latter can

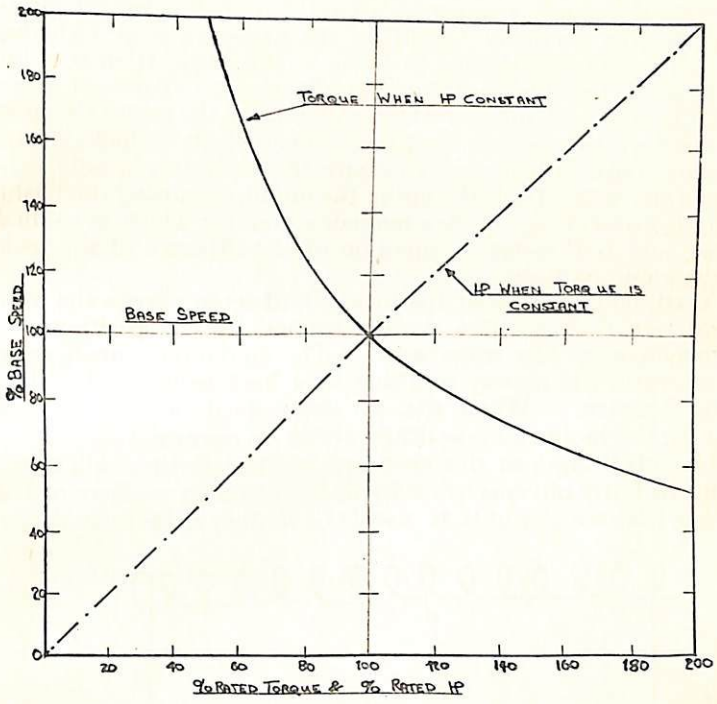


**Fig. 31.**

warm up; then when the jockey-weight moves sufficiently far along the beam to give sufficient movement to the jockey-weight arm to depress the remote control switch, and the panel has tripped in, the forward contactor on electronic panel will energise, and the motor will begin to turn and take up the load gradually. When the position of balance is reached due to the application of this load, that is when the load on the main beam balances the load movement of the jockey-weight arm, the remote control switch will be released and the contactor on the main panel will be de-energised, thus stopping the motor.

The motor will be quickly brought to rest, because as soon as the forward contactor is released a braking contactor is energised and places a low value resistance across the armature circuit of the motor and absorbs the back E.M.F. of the motor and quickly brings it to rest. If, however, the out-balance load is excessive, the jockey-weight arm will pass through the balance position and operate the upper remote control switch, which in turn will reverse the motor and decrease the load.

While the panel is warming up and the jockey-weight motor is operating, the small pilot light on the upper extreme right-hand-side of the panel continues to flash. This innovation was found necessary to indicate visually that the small jockey-lead screw is revolving, and is accomplished by attaching to the end of the jockey-lead screw an 18 lobe cam, operating a micro switch which interrupts the pilot lamp. Being in series with the secondary winding of the transformer which feeds the lamp, the impulses causing the flashing-lamp also operate an electro-magnetic counter which is calibrated in lbs., and is therefore a function of the distance of the jockey-weight along its beam.

It will be realised that the jockey-lead screw carries the jockey-weight out to a position pre-determined by the position of the micro-switch on the beam arm. The contactors, upon closure, will energise the motor, resulting in a load being applied to the spring balance. When the pre-determined weight has been reached, the motor automatically ceases to operate.

The advantages of this electronic control method will now, no doubt, be fairly obvious, since by its employment we have rectification so that we are able to use D.C. motors with their desirable

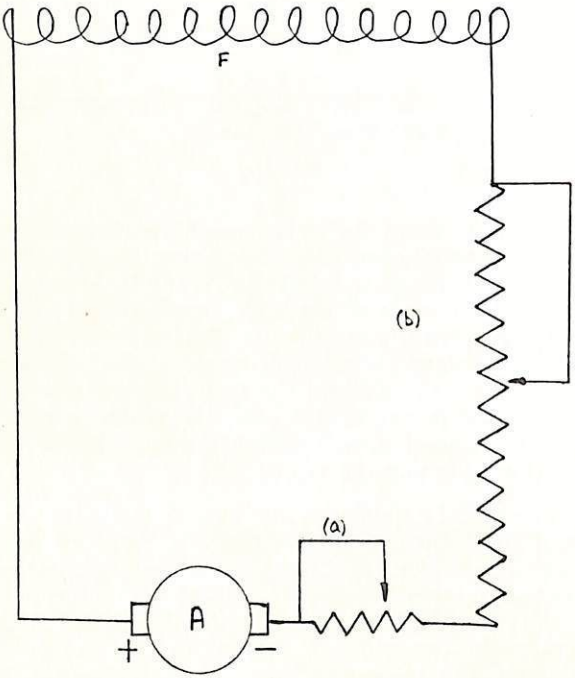


**Fig. 32.**

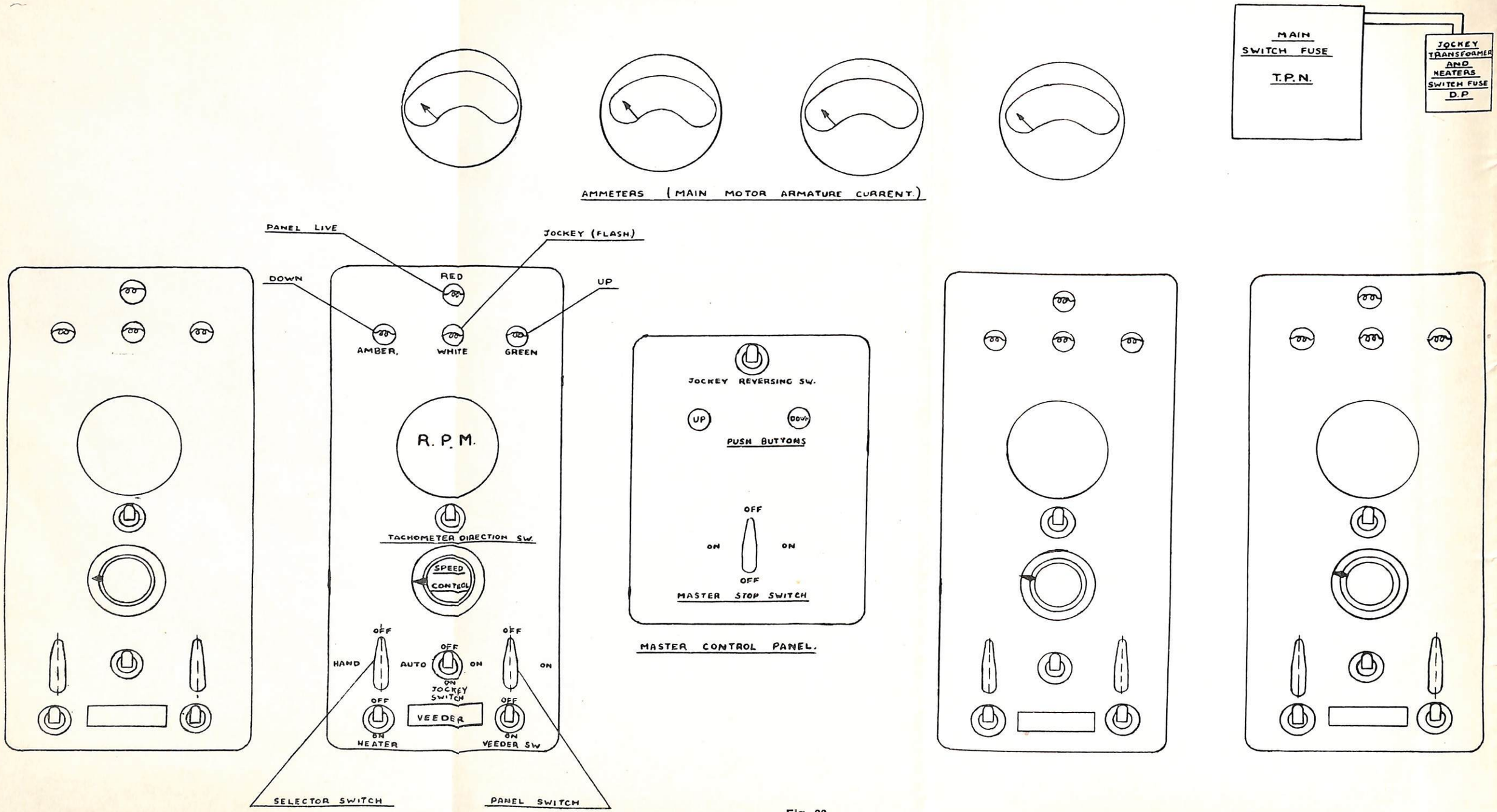
MAIN
SWITCH FUSE
T.P.N.
JOCKEY
TRANSFORMER
AND
HEATERS
SWITCH FUSE
D.P
AMMETERS (MAIN MOTOR ARMATURE CURRENT.)
PANEL LIVE
JOCKEY (FLASH)
DOWN
RED
UP
AMBER.
WHITE
GREEN
R.P.M.
TACHOMETER DIRECTION SW.
SPEED
CONTROL
OFF
HAND
AUTO
ON
OFF
ON
JOCKEY
SWITCH
OFF
ON
HEATER
VEEDER
OFF
ON
VEEDER SW
SELECTOR SWITCH
PANEL SWITCH
JOCKEY REVERSING SW.
UP
DOWN
PUSH BUTTONS
OFF
ON
ON
OFF
MASTER STOP SWITCH
MASTER CONTROL PANEL.

Fig. 33.

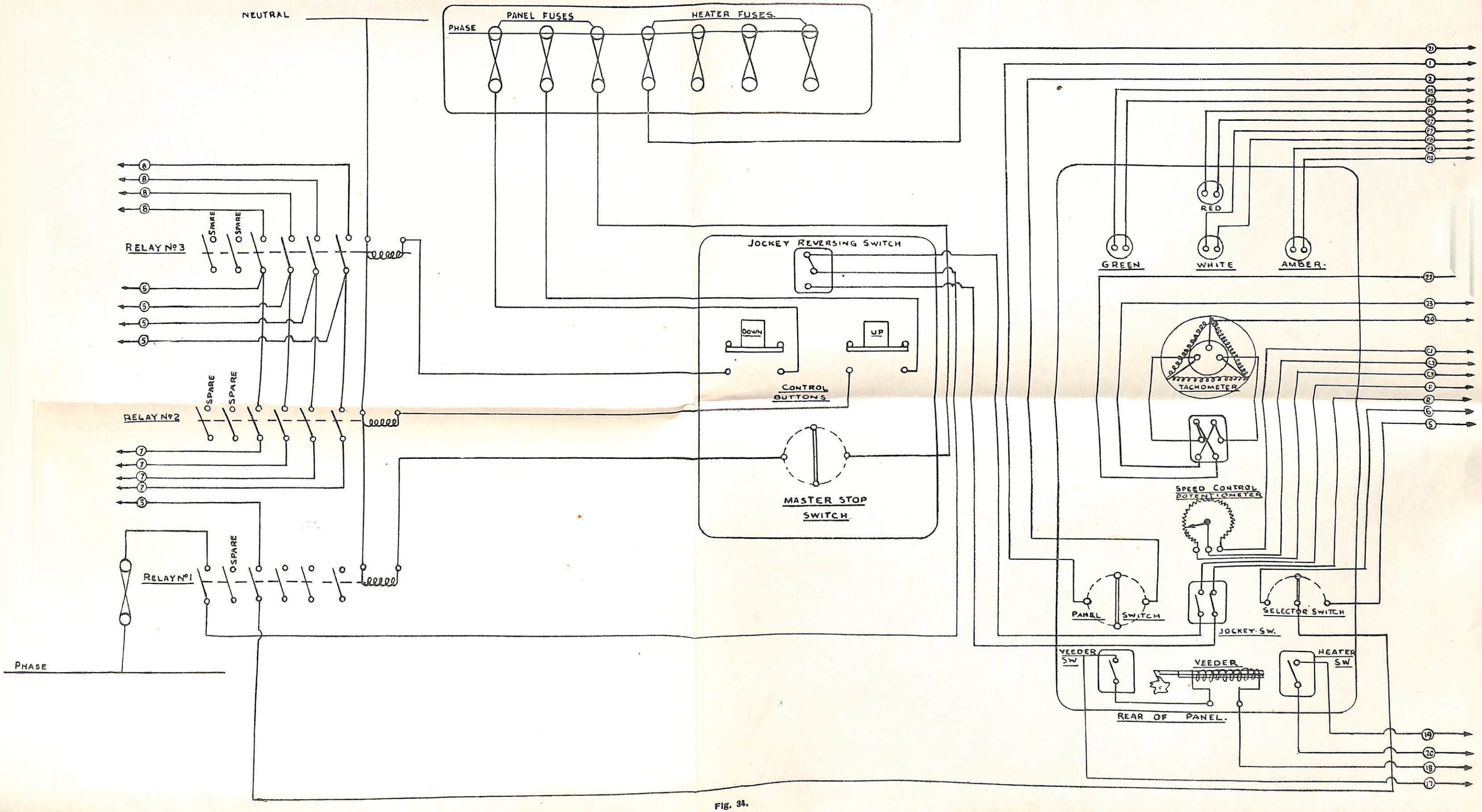
NEUTRAL
PHASE
PANEL FUSES
HEATER FUSES.
RELAY Nº3
RELAY Nº2
RELAY Nº1
OSPARE
JOCKEY REVERSING SWITCH
DOWN
UP
CONTROL BUTTONS
MASTER STOP SWITCH.
RED
GREEN
WHITE
AMBER.
TACHOMETER
SPEED CONTROL POTENTIOMETER
PANEL SWITCH
JOCKEY SW.
SELECTOR SWITCH
VEEDER SW
VEEDER
HEATER SW
REAR OF PANEL.

Fig. 34.

## ABBEY TEST FRAME

### ELECTRONIC CONTROL PANEL WIRING DIAGRAM (SCHEMATIC.)

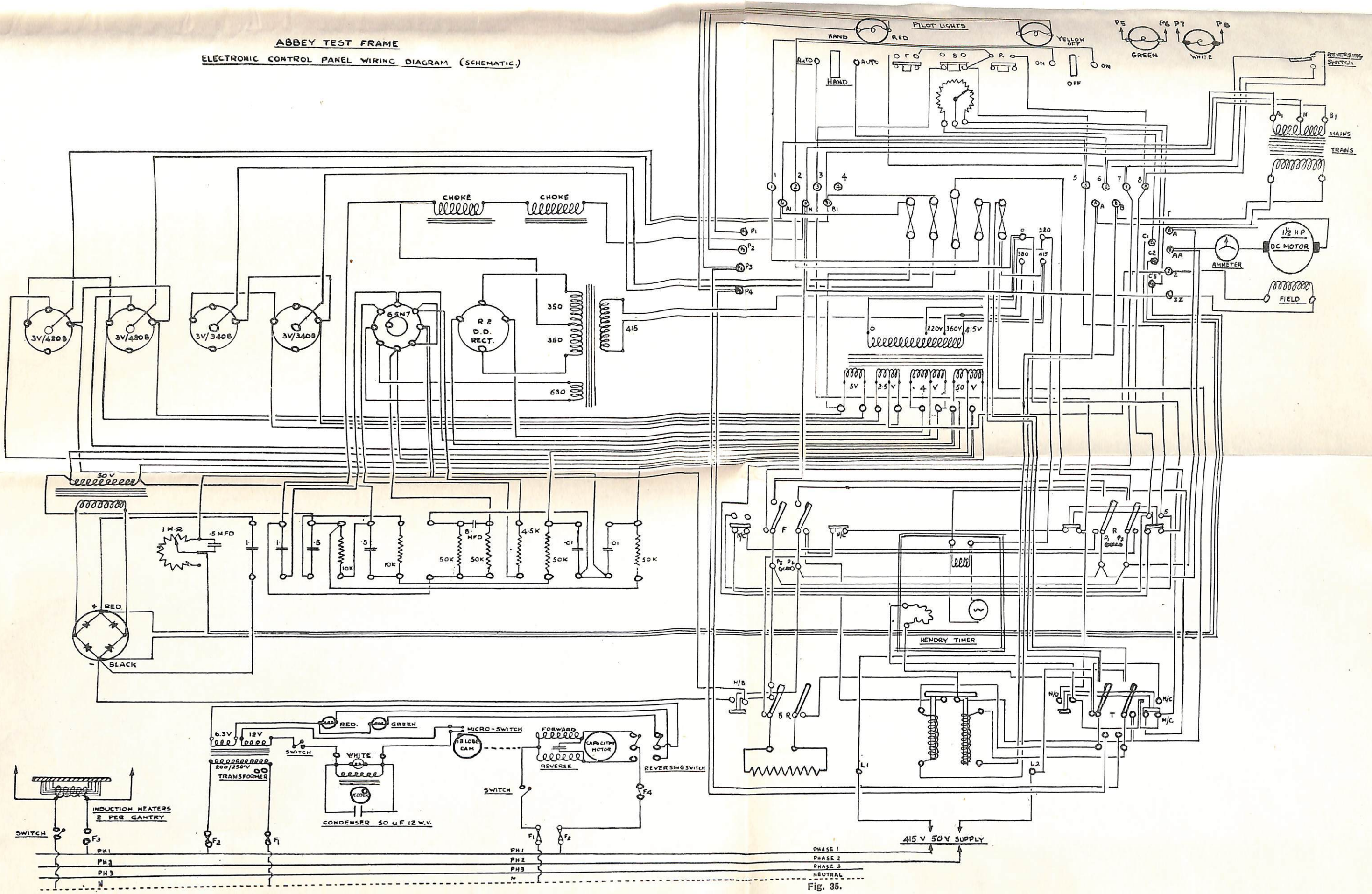


Fig. 35.

characteristics, stepless speed control, dynamic braking, instantaneous reversal, and remote control, also constant speed at various torque applications, provided of course that these applications are within the rated H.P. of the motor, without the use of Ward-Leonard apparatus, or motor generator sets.

If we refer to Fig. 32 we will see that with an ordinary shunt motor we can crudely control the speed, by using a rheostat in the armature circuit, and varying it as required, but the current through the rheostat would be the same as the current through the armature and as much wattage would be developed across this resistance as across the motor. Moreover as the current in the armature increased because of an increase of load, the voltage drop across the resistance would also increase and the speed would change, consequently the resistance would have to be adjusted for each change of load. We could also put a resistance in the field circuit as shown in Fig. 32. This would enable us to increase the speed above base speed but not below it. The resistance shown in Fig. 32 would allow us to increase the speed up to base speed, but not above it. From this fact alone the advantages of electronic control outweigh such methods as the Ward-Leonard system, in which the motor drives the generator and the controlled output of the generator drives the motor to which the load is connected.

So far we have considered these panels as individual units, but for the purposes of testing a major component all the four panels are controlled from a central master panel, which is shown in Fig. 33. The controls on each panel are set to a pre-determined position before switching on the central panel; the control to the four panels is then simultaneous.

It will be noticed by reference to Fig. 33 and Fig. 34 that the individual push buttons, shown earlier, on each panel have been replaced by two master push buttons on the central panel.

The separate push buttons have been replaced by the relays shown in Fig. 34.

The jockey motors are controlled by a master switch, using the same relay system.

Fig. 35 is the main wiring diagram of one panel only, and the connection numbers shown therein correspond to the connection numbers shown in the control panel wiring, Fig. 34.

Fig. 33 shows the panel layout for operational purposes.

Electromagnetic induction heaters are fitted to the main pivoting points to keep the friction constant. These are depicted in the lower left-hand corner of Fig. 35.

In the event of a specimen failing, or any undesired effect, the master stop switch can be operated to bring everything to a standstill, without actually switching the panels off and involving a reheating period for the valves.

**Conclusion.**

It is felt that no apologies are necessary for the brevity of description in the foregoing text, because, as stated at the inception, it was intended to be introductory. If, however, resort is made to those books listed in the bibliography, this pamphlet will have achieved its purpose.

The books contained therein are mainly American, since so much is done in the U.S.A. by electronic means that they are based on a wealth of practical experience.

The advantages of electronic technique are not limited to the industrial field by any means, but can claim to be applicable to practically the whole field of human endeavour in one way or another.

The bibliography in each of the books shown in the list will indicate the ramifications of the subject.

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The following books are recommended for further study :—

*Electronics in Industry*, by George M. Chute, McGraw-Hill Co. Inc.
*Cathode Ray Oscillographs*, by J. H. Reyner, Sir Isaac Pitman & Sons, Ltd.
*Text Book of Electronics*, by J. M. Lenihan, English University Press.
*Electron Tubes in Industry*, by K. Henney, McGraw-Hill Co. Inc.
*Engineering Electronics*, by G. D. Fink, McGraw-Hill Co. Inc.
*Fundamentals of Electronics and Vacuum Tubes.*
*Industrial Electronics*, by W. D. Cockrell, John Wiley & Sons.
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23. 1″ ,, ,, ,, ,,
24. ¾″ Sq. Steel Tubes as Struts (30 ton yield).
25. ⅞″ ,, ,, ,, (30 ton yield).
26. 1″ ,, ,, ,, (30 ton yield).
27. ¾″ ,, ,, ,, (40 ton yield).
28. ⅞″ ,, ,, ,, (40 ton yield).
29. 1″ ,, ,, ,, (40 ton yield).
30. Moments of Inertia of Built-up Sections (Tables) }
31. Moments of Inertia of Built-up Sections (Instructions and Examples) } Connected.
32. Reinforced Concrete Slabs (Line Chart) }
33. Reinforced Concrete Slabs (Instructions and Examples) } Connected.
34. Capacity and Speed Chart for Troughed Band Conveyors.
35. Screw Propeller Design (Sheet 1, Diameter Chart) }
36. ,, ,, ,, (Sheet 2, Pitch Chart) } Connected.
37. ,, ,, ,, (Sheet 3, Notes and Examples) }
38. Open Coil Conical Springs.
39. Close Coil Conical Springs.
40. Trajectory Described by Belt Conveyors. (Revised, 1949).
41. Metric Equivalents.
42. Useful Conversion Factors.
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44. Railway Vehicles on Curves.
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46. Coned Plate Developments.
47. Solution of Triangles (Sheet 1, Right Angles),
48. Solution of Triangles (Sheet 2, Oblique Angles).
49. Relation between Length, Linear Movement and Angular Movement of Lever (Diagram and Notes).
50. ,, ,, ,, ,, ,, ,, (Chart).
51. Helix Angle and Efficiency of Screws and Worms.
52. Approximate Radius of Gyration of Various Sections.

W. E. Stewart.

53. Helical Spring Graphs (Round Wire)
54. " " " (Round Wire)
55. " " " (Square Wire)
} Connected.
56. Relative Value of Welds to Rivets.
57. Ratio of Length/depth of Girders for Stiffness.
58. Graphs for Strength of Rectangular Flat Plates of Uniform Thickness.
59. Graphs for Deflection of Rectangular Flat Plates of Uniform Thickness.
60. Moment of Resistance of Reinforced Concrete Beams.
61. Deflection of Leaf Spring.
62. Strength of Leaf Spring.
63. Chart showing Relationship of Various Hardness Tests.
64. Shaft Horse Power and Proportions of Worm Gear.
65. Ring with Uniform Internal Load (Tengential Strain)
66. Ring with Uniform Internal Load (Tangential Stress)
} Connected.
67. Hub Pressed on to Steel Shaft. (Maximum Tangential Stress at Bore of Hub).
68. Hub Pressed on to Steel Shaft. (Radial Gripping Pressure between Hub and Shaft).
69. Rotating Disc (Steel) Tangential Strain
70. " " " Stress
} Connected.
71. Ring with Uniform External Load, Tangential Strain
72. " " " " " Stress
} Connected.
73. Viscosity Temperature Chart for Converting Commercial to Absolute Viscosities.
74. Journal Friction on Bearings.
75. Ring Oil Bearings.
} Connected.
76. Shearing and Bearing Values for High Tensile Structural Steel Shop Rivets, in accordance with B.S.S. No. 548/1934.
77. Permissible Compressive Stresses for High Tensile Structural Steel, manufactured in accordance with B.S.S. 548/1934.
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